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New 8-bit Microcontrollers with integrated configurable logic in 6- to 20-pin packages

Microchip's new PIC10F/LF32X and PIC12/16F/LF150X 8-bit microcontrollers (MCUs) let you add functionality, reduce size, and cut the cost and power consumption in your designs for low-cost or disposable products, with on-board Configurable Logic Cells (CLCs), Complementary Waveform Generator (CWG) and Numerically Controlled Oscillator (NCO).

The Configurable Logic Cells (CLCs) give you software control of combinational and sequential logic, to let you add functionality, cut your external component count and save code space. Then the Complementary Waveform Generator (CWG) helps you to improve switching efficiencies across multiple peripherals; whilst the Numerically Controlled Oscillator (NCO) provides linear frequency control and higher resolution for applications like tone generators and ballast control.

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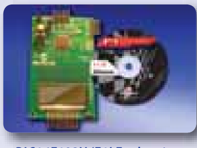
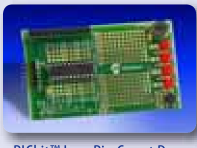


PIC16F193X 'F1' Evaluation Platform - DM164130-1



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VOL. 40. No 12 December 2011

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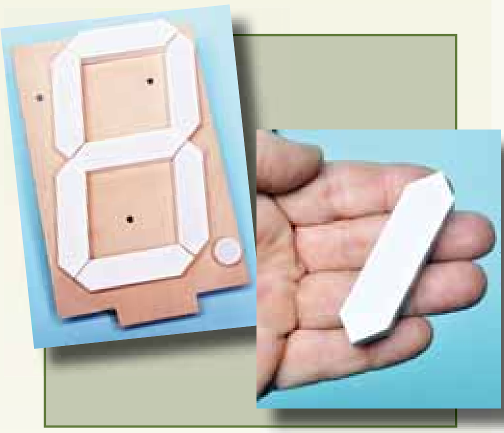
Projects and Circuits

Series and Features



Regulars and Services

Our January 2012 issue will be published on Thursday 8 December 2011, see page 72 for details.

LED Roulette Kit - £18.95
Order Code MK119KT
Solar Bug Kit - £17.95
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Robot Kits
These educational electronic robot kits make a great introduction to the exciting world of robotics. Some require soldering. See website for details
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Don't Just sit there - Build Something This Christmas

KIT OF THE MONTH

Ultrasonic Antifouling Kit for Boats

KC-5498 £90.50 plus postage & packing

Marine growth electronic antifouling systems can cost thousands. This project uses the same ultrasonic waveforms and virtually identical ultrasonic transducers mounted in sturdy polyurethane housings. By building it yourself (which includes some potting) you save a fortune! Standard unit consists of control electronic kit and case, ultrasonic transducer, potting and gluing components and housings. The single transducer design of this kit is suitable for boats up to 10m (32ft); boats longer than about 14m will need two transducers and drivers. Basically all parts supplied in the project kit including wiring. (Price includes epoxies).

- 12VDC
- Suitable for power or sail
- Could be powered by a solar panel/wind generator
- PCB: 78 x 104mm

Clifford The Cricket Kit

KC-5178 £6.25 plus postage & packing

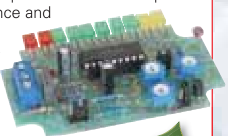
Clifford hides in the dark and chirps annoyingly until a light is turned on - just like a real cricket. Clifford is created on a small PCB, measuring just 40 x 35mm and has cute little LED insect eyes that flash as it sings. Just like a real cricket, it waits a few seconds after darkness until it begins chirping, and stops instantly when a light comes back on.

- PCB, piezo buzzer, LDR plus all electronic components supplied
- PCB: 40 x 35mm

Top Seller

Voltage Monitor Kit

KC-5424 £8.50 plus postage & packing



This versatile kit will allow you to monitor the battery voltage, the airflow meter or oxygen sensor in your car. The kit features 10 LEDs that illuminate in response to the measured voltage, preset 9-16V, 0.-5V or 0-1V ranges, complete with a fast response time, high input impedance and auto dimming for night time driving. Kit includes PCB with overlay, LED bar graph and all electronic components.

- 12VDC
- PCB: 74 x 47mm

Featured in EPE September 2010

SFX Kits

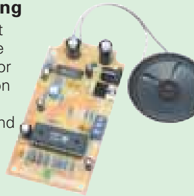
Theremin Synthesiser Kit MkII

KC-5475 £27.25 plus postage & packing

The ever-popular Theremin is better than ever! From piercing shrieks to menacing growls, create your own eerie science fiction sound effects by simply moving your hand near the antenna. It's now easier to build with PCB-mounted switches and pots to reduce wiring to just the hand plate, speaker and antenna and has the addition of a skew control to vary the audio tone from distorted to clean.

- Complete kit contains PCB with overlay, pre-machined case and all specified components
- PCB: 85 x 145mm

Starship Enterprise Door Sound Emulator Kit KC-5423 £14.50 plus postage & packing



This easy to build kit emulates the unique sound of a cabin door opening or closing on the Starship Enterprise. The sound can be triggered by switch contacts or even fitted to automatic doors.

- Kit supplied with PCB with overlay, speaker, case and all specified components
- 9-12VDC regulated

SD/MMC Card Web Server In a Box

KC-5489 £32.75 plus postage & packing

Host your own website on a common SD/MMC card with this compact Web server In a Box (WIB). Connecting to the Internet via your modem/router, it features inbuilt HTTP server, FTP server, SMTP email client, dynamic DNS client, RS232 serial port, four digital outputs and four analogue inputs. Requires a SD memory card, some SMD soldering and a 6 - 9VDC adaptor.

- Kit includes PCB, case and electronic components
- PCB: 123 x 74mm

Speedo Corrector MkII Kit

KC-5435 £20.00 plus postage & packing

Modifying your gearbox, diff ratio or changing to a larger circumference tyre may result in an inaccurate speedometer. This kit readjusts the speedometer signal up or down from 0% to 99% of the original signal. This upgraded model enables automatic input setup selection and indicates when the input signal is being received. Kit supplied with PCB with overlay and all electronic components.

- PCB: 105 x 61mm
- Recommended box UB5 use (HB-6013 £1.50).

DC Relay Switch Kit

KC-5434 £6.25 plus postage & packing

An extremely useful and versatile kit that enables you to use a tiny trigger current - as low as 400µA at 12V to switch up to 30A at 50VDC. It has an isolated input, and is suitable for a variety of triggering options. The kit includes PCB with overlay and all electronic components with clear instructions.

FANTASTIC Stocking Fillers

Short Circuits - Volume 1

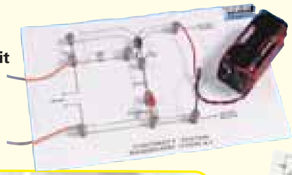
An excellent way for new comers to dip their toes into the wonders of electronics!

This volume will teach you everything you need to get started in electronics and is suitable for ages 8+. We give you the option of buying the book on its own, or together with the accompanying kit that contains the components for each of the 20-odd projects described in the book. Some of the exciting projects include a Police Siren, Electronic Organ, Sound Effects Unit, Light Chaser and many, many more! The full colour 96 page book, is lavishly illustrated with over 100 drawings and diagrams. No prior knowledge of electronics is needed, projects are fun and safe to build.

Short Circuits Book
BJ-8502 £3.75

Short Circuits Project Kit
KJ-8504 £12.50

Short Circuits Book and Project Kit
KJ-8502 £14.50



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AGES 8+

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- **Minimum order £10**

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Non volatile flash memory, Single 20 sec recording via integral mic, 2W output to 8Ω speaker.
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C-9701 Cebek Module £7.89
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Works with any incandescent or LED rear centre brake light. Flashes at 7Hz for 5 or 10 times, adjustable retriggering.
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MK178 Velleman kit £6.30
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An up or down counter via on-board button or ext input. Time display feature. Alarm count output. 0-9999 display.
Power: 9-12Vdc 150mA
K8035 Velleman kit £17.85
2 Digital Counter
Standard counter, 0 to 99 from input pulses or external signal. With reset input, 13.5mm Displays,
Power: 12Vdc 90mA.
CD-9 Cebek Module £12.99
Digital Clock Mini Kit
Red 7 Segment display in attractive enclosure, automatic time base selection, battery back-up, 12 or 24Hr modes.
Power: 9Vac or dc
MK151 Velleman kit £15.09
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Gas filled nixie tubes with their distinctive orange glow. HH:MM display, automatic power sync 50/60Hz
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K8099 Velleman kit £64.96
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Compact mono 1.8W RMS 4Ω power stage, short circuit & reverse polarity protection. 30-18kHz, Power: 4-14Vdc 150mA
E-1 Cebek Module £5.87
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A simple security kit with many applications. RFID technology activates a relay, either on/off or timed. Supplied with 2 cards, can be used with up to 25 cards. Power: 9Vac or dc
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Mini USB Interface Board
New from Velleman this little interface module with 15 inputs/outputs inc digital & analogue in, PWM outputs. USB Powered 50mA, Software supplied
VM167 Module £26.80
20W 2 Channel Amplifier
Mono amplifier with 2 channels (Low & High frequency), 20W RMS 4Ω per channel, adjustable high level. 22-22kHz, short circuit & reverse polarity protection.
Power: 8-18Vdc 2A
E-14 Cebek Module £22.11
Running Microbug Kit
Powered by two subminiature motors, this robot will run towards any light source. Novel shape PCB with LED eyes.
Power: 2 x AAA Batteries
MK127 Velleman kit £9.02
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Power: 12Vdc 100mA
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Stereo power stage with 5W RMS 4Ω, 30-18kHz, short circuit & reverse polarity protection.
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ES-2 Cebek Module £21.54
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A high quality audio power amp, 200w music power @ 4Ω 3-200kHz Available as a kit without heatsink or module including heatsink.
K8060 Velleman kit £12.85
Heatsink for kit £9.95
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Single rail regulated power supply complete with transformer. 130mA max, low ripple, 12Vdc with adjustment.
FE-103 Cebek Module £13.16
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Plays MP3 files from an SD card, supports ID3 tag which can be displayed on optional LCD. Line & headphone output. Remote control add-on. Power: 12Vdc 100mA
K8095 Velleman kit £39.99
Velleman PC Scope
PC Based USB controlled 2 channel 60Mhz oscilloscope with spectrum analyser & Transient recorder. 2 Scope probes & software included. See web site for full feature list.
PCSU1000 Velleman £249.00
1-180 Second Timer
Universal timer with relay output. Time start upon power up or push button. LED indication. 5A Relay
Power: 12Vdc 60mA
I-1 Cebek Module £12.92
DC to Pulse width Modulator
A handy kit to accurately control DC motors etc. Overload & short circuit protection. Input voltage 2.5-35Vdc, Max output 6.5A.
Power: 8-35Vdc
K8004 Velleman kit £9.95
Velleman PC Scope/Generator
PC Based USB controlled 2 channel oscilloscope AND Function generator. Software included. See web site for full feature list.
PCSGU250 Velleman £113.67
Cyclic Timer
Universal timer with relay output. Time start upon power up or push button. On & Off times 0.3-60 Seconds, LED indication. 5A Relay
Power: 12Vdc 80mA
I-10 Cebek Module £14.12
Audio Analyser Kit
A small spectrum analyser with LCD. Suitable for use on 2, 4 or 8Ω systems. 300mW to 1200W(2Ω) 20-20kHz Panel mounting, back-lit display. Power: 12Vdc 75mA
K8098 Velleman kit £31.65
RF Remote Control Transmitter
Single channel RF keyfob transmitter with over 13,122 combinations. Certified radio frequency 433.92MHz.
Power: 12Vdc 2mA (inc) For use with TL-1,2,3,4 receivers.
TL-5 Cebek Module £14.64
Light Detector
Adjustable light sensor operating a relay. Remote sensor & terminals for remote adjustment pot. 5A Relay
Power: 12Vdc 60mA
I-4 Cebek Module £13.98
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USB DMX Interface
512 DMX Channels controlled by PC via USB. Software & case included. Available as a kit or ready assembled module.
K8062 Velleman kit £47.90
VM116 Module £67.15
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Power: 12Vdc 60mA For use with TL-5 or TL-6 transmitters.
TL-1 Cebek Module £28.25
Liquid Level Detector
A liquid level operated relay. Remote sensor operates relay when in contact with a liquid. 5A Relay
Power: 12Vdc 60mA
I-6 Cebek Module £13.08
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USB
Featuring 5 in, 8 digital outputs, 2 in & 2 analogue outputs. Supplied with software. Available as a kit or ready assembled module.
K8055 Velleman kit £24.80
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An electronic lock with up to ten 4 digit codes. Momentary or timed (1-60ec/1-60min) output. Relay 5A
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DA-03 Cebek Module £54.26
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I-8 Cebek Module £12.80
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Power: 230Vac
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All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in EPE employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.

COMPONENT SUPPLIES
We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers.

We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

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Looking ahead to 2012

Well, it's that funny time of year (the beginning of October as I write this) when the *publishing* year changes and I start to look to 2012, even though we have the best part of three months left to run in 2011. I have spent the last few days drawing up lists of articles, calculating pagination and running order, and generally wondering how we will fit it all in.

So, the obvious question is what do we have to look forward to next year?

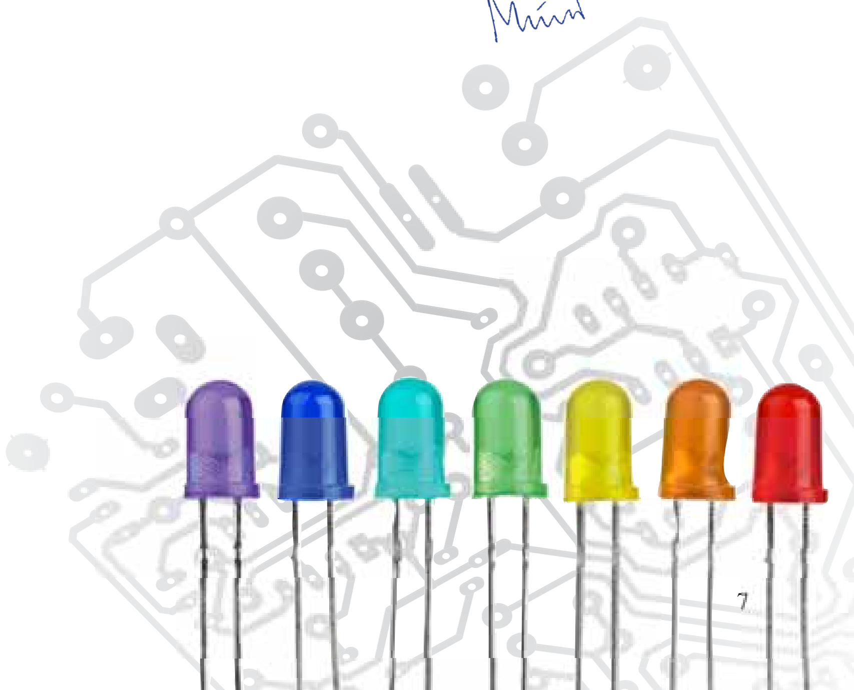
The answer is, 'a lot'! There is a really exciting collection of projects queuing up to appear in *EPE*. I don't want to spoil the fun by revealing all the goodies that will come your way, but a small taster does no harm. Still, as they say when announcing football results, if you don't want to know… look away now.

We have some great bench gear for you to build. For example, there will be a super-accurate thermometer; probes and adaptors to extend the use and functionality of your digital multimeter; and a 16-bit digital potentiometer.

Audio is never far from the heart of *EPE*, and you won't be disappointed with next year's offering. From a high performance microphone preamplifier and compact 20W stereo amp to a fantastically flexible signal generator, there will be plenty to keep hi-fi enthusiasts busy. DAB radio will make an appearance too, with a satisfying three-part project.

Then there are the projects that don't really fit into any category, but which are nevertheless fun and useful: an RFID security system; an air quality meter to check CO and CO_2 levels; and a boat ultrasonic antifouling unit for the mariners out there. The year will finish off with a superb and very original project in the shape of a digital Christmas lighting controller that will give your decorations an amazing blast of colourful fun.

All this and much more will be in the 12 bumper issues of next year's *EPE* – don't miss out, take out a subscription now, and save money!



NEWS

A roundup of the latest Everyday News from the world of electronics

Magnet prices repel speaker manufacturers by Barry Fox

The price of rare earth magnetic material neodymium has rocketed over recent months – by as much as 1000%. The makers of compact speakers, high fidelity tweeters, microphones, mobile phones and hybrid vehicle motors must either pay up or try to redesign for less efficient magnets.

Neodymium is not a particularly rare 'rare earth', and is known to exist in Australia, Africa, Russia, under the sea off Japan and in several western US states. But environmental concerns, such as toxic wastewater running off from the mining process, has left China the only country with neodymium mines willing to risk public health for high cash returns.

As a result, neodymium is now almost exclusively mined in China, and last year the country imposed an unofficial export embargo, raised taxes from less than 50 cents per kilogram to $8 per kilogram of refined product. It also announced that it would not approve new mining projects until after 2015.

When neodymium was affordable, designers used it liberally, building mounts and cabinets that will not work with less efficient and thus larger magnets made from ferrite, ceramics or alnico (aluminium, nickel and cobalt alloy).

Apart from size and weight – which is an important issue for car components – lesser magnets will not secure a grille designed for neodymium.

British loudspeaker company KEF is now owned by Chinese investors, but this does not shield them from neodymium magnet price hikes and shortages. 'It's the same for everyone', MD Steve Halsall explained at a lunch in London called to celebrate KEF's 50th anniversary. 'The only difference is that we could spot the issue earlier.'

'You can design neodymium out of mid and bass drivers, and use ferrite, because size is not critical. That's what we have done and it's what most companies now have to do. But you can't make tweeters like our Uni-Q point source driver array without neodymium. The material is ten times more powerful than conventional magnetic materials. That's what allowed us to engineer a tweeter small enough to mount at the acoustic centre of bass or mid-range voice coils so that both act as one.'

'Neodymium was the reason for the Uni-Q, so we will just have to pay whatever it costs to use it. The saving grace is that some of the speakers that use Uni-Q drivers cost 26,000 euros a pair, so the cost of the magnet is only a fraction of the price.'

'Our sister company Celestion is affected more because it concentrates on making drivers. Before long, everyone will have changed production to avoid neodymium – except for designs where size is super critical.'

So, although in the short term Western concern for the environment is earning China huge rewards, in the longer term, China's predatory pricing looks likely to backfire, because manufacturers will find alternative materials and designs.

New from Pico

Three new oscilloscopes in the PicoScope 2000 Series are the first USB-powered oscilloscopes to offer a real-time sampling rate of 1GS/s. With two channels, bandwidths ranging from 50MHz to 200MHz, a built-in function generator, arbitrary waveform generator and external trigger input, these compact and economical scopes are perfect for hobbyists needing a complete test bench in a single unit.

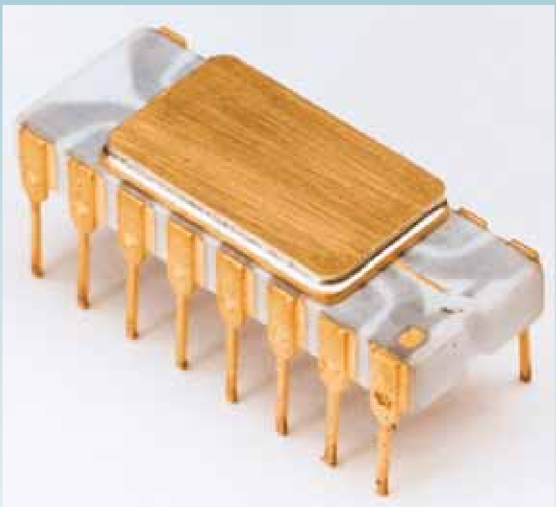
The scopes are supplied with a full version of the PicoScope oscilloscope software. As well as standard oscilloscope and spectrum analyser functions, PicoScope includes valuable features such as serial decoding, mask limit testing, segmented memory and advanced triggers. It provides a large, clear display that shows waveforms in great detail and allows easy zooming and panning. Other features include maths channels, automatic measurements and decoding of I²C, UART/RS232, SPI and CAN bus data.

The new scopes use digital triggering, which ensures lower jitter, greater accuracy and higher resolution than the analogue triggers found on many other scopes. The advanced trigger types include pulse width, interval, window, window pulse width, level dropout, window dropout, runt pulse, variable hysteresis, and logic.

A free software development kit allows users control from custom applications. Included are example programs in C, C++, Excel and LabVIEW.

Prices range from £349 for the 50MHz PicoScope 2206 to £599 for the 200MHz PicoScope 2208, including a five-year warranty. For more details, see: **www.picotech.com**

Happy 40th to Intel's 4004 microprocessor



The Intel 4004, the first-ever user-programmable microprocessor

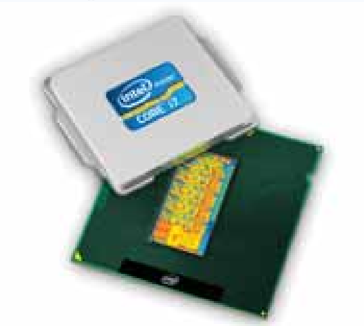
This month sees a very special 40th birthday for all involved in electronics. On 15 November 1971, Intel created the first customer-programmable microprocessor, the *Intel 4004*.

It was originally conceived as a software-defined alternative to a full custom chipset for a business calculator, but the flexibility of the 4004 meant that other uses were quickly found for it, and it became the brains for a variety of products, from gas pumps to traffic light controllers. Since then, multiple generations of Intel microprocessors have followed, including the Intel 8086 microprocessor in 1978, which powered the first IBM Personal Computer and quite literally changed the world.

Microprocessors have been one of the leading beneficiaries of 'Moore's Law', whereby the number of transistors that can be placed inexpensively on a given area of silicon real estate doubles every couple of years. This seems especially appropriate for microprocessors, since Gordon Moore, who proposed the 'law' was a co-founder of Intel in 1968.

To celebrate this extraordinary growth in microprocessor complexity and power, Intel have released some 'Fun Facts'.

- Comparing the speed of the first microprocessor's transistor with the latest generation transistors, is like comparing the speed of a snail (5m/h) with the speed of the Kenyan runner Patrick Makau Musyoki in his record-breaking marathon run (42,195 meters at 2:03:38 hours or an average of 20.6km/h).
- Today, the average annual energy cost to power a modern laptop is about £22. If the energy consumption had remained unchanged since 1971, today's laptops would consume 4000 times more energy and cost about £90,000 per year.
- The die of the 4004 processor consisted of 2300 transistors. The current 2nd gen Intel Core i7 processor has almost one billion transistors. This is like comparing the population of a large village to the population of China. Had today's 2nd gen Intel Core processor (actual size: 216mm^2) been manufactured in the historic 10µm process technology, it would be 21m^2, or roughly 7m × 3m.
- The Intel 4004 microprocessor ran at 740kHz (the current 2nd generation of Intel Core processors achieves almost 4GHz. If the velocity of speedboats had increased at the same pace since 1971, it would take about one second to go from London to New York, assuming the boat speed in 1971 was 60 miles/hour and the distance between London and New York is 3000 miles.
- Compared to Intel's first microprocessor, the 4004, Intel's current 32nm CPU runs almost 5000 times faster and each transistor uses about 5000 times less energy. In the same period, the price of a transistor has dropped by a factor of about 50,000.
- The original transistor built by Bell Labs in 1947 was large enough that it was pieced together by hand. By contrast, more than 6 million 22nm tri-gate transistors could fit in the full stop at the end of this sentence.



2nd generation Intel Core i7 processor (32nm)

EasyPICings

The successor to mikroElektronika's major development board for PIC microcontrollers has been released – the EasyPIC v7.

For the first time in EasyPIC's near 10-year history, EasyPIC v7 has grouped PORT headers, LEDs and Buttons in Input-Output groups, thus making them easier to use than ever before. The boards are equipped with tri-state DIP switches, so placing pull-up or pull-down jumpers to desired pins is now just a matter of pushing the switch.

The new board has a dual power supply, supporting both 3.3V and 5V microcontrollers.

Probably the best feature of the board is the powerful on-board mikroProg programmer and In-Circuit debugger, capable of programming over 250 PIC microcontrollers. Debugging is supported with all mikroElektronika PIC compilers – mikroC, mikroBasic and mikroPascal.

A special feature is the three displays: GLCD 128x64, LCD 2x16 character and 4-digit 7-seg displays. Other useful details include new modules for: serial EEPROM, a piezo buzzer and support for both DS1820, and LM35 temperature sensors.

Last, but by no means least, the EasyPIC v7 user manuals and schematics have been redesigned. Documentation is now more informative, with lots of clear photos, good explanations and well thought organisation. For more information, see: **www.mikroe.com/eng/products/view/757/easypic-v7-development-system**

mikroElektronika: apologies to readers of EPE *magazine*

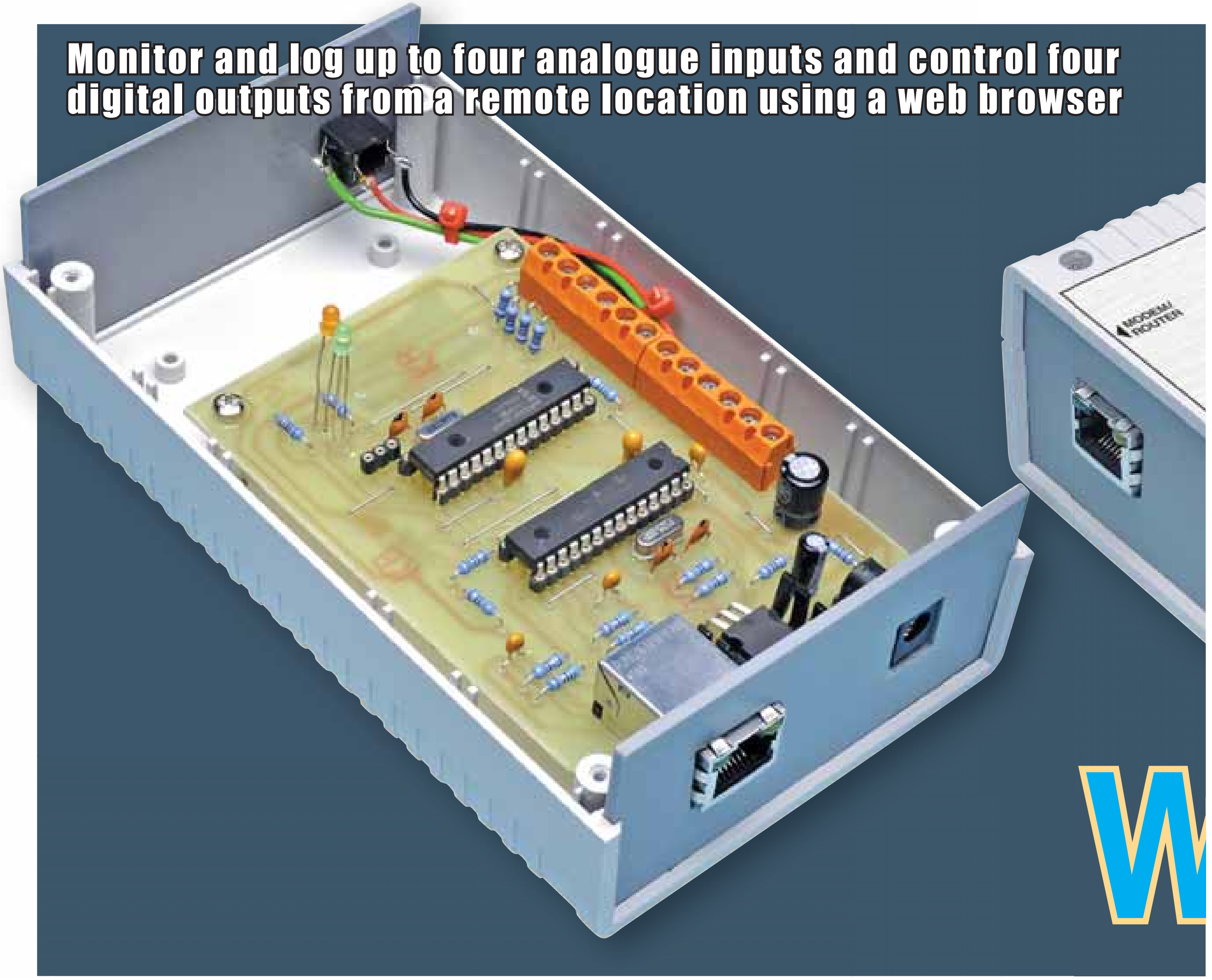
In the November edition of EPE*, mikroElektronika advertised the new EasyPIC v7 board. Unfortunately, the advertisement included an incorrect price for the board. Instead of $139, as stated in the ad, the price of the board is $149. We are very sorry for this mistake, and apologise to everyone affected.*

We will continue to provide only the highest quality products and services with the correct information, as always – mikroElektronika

New low pressure sensors

Sensirion has launched two new versions of its differential pressure sensors in the SDP600 series. New sensors SDP6x0-125Pa and SDP6x0-25Pa feature very low measurement ranges of –125 to +125Pa and –25 to +25Pa. For more data see: **www.sensirion.com/sdp6x0**

Monitor and log up to four analogue inputs and control four digital outputs from a remote location using a web browser



We're very excited about this project. It will let you house your own website with possibly hundreds or even thousands of pages, all in a little box connected to the Internet via your modem/router.
You don't need a computer to operate and house a website – this little box does it for you, and it can be accessed from anywhere in the world, at any time, even from a mobile phone which has a web browser. In fact, it is a complete web server in a box – so we've called it WIB (*W*eb server *I*n a *B*ox).

EVERYONE knows that web servers normally involve big, expensive, powerful computers with large memory, large hard disks and exotic software, don't they? Well, that is the normal approach, but now it doesn't have to be. In fact, you don't even need a computer!

WIB can do it all. Even better, it does not have a hard disk, uses practically no power and costs not much at all. WIB is just a small PC board (single-sided, no less) with a microcontroller, an SD/MMC card reader and not much else. In fact, it involves a total of just three ICs and a 3-terminal regulator.

Why have a memory card? This is the 'Eureka!' feature: SD/MMC cards are used in the majority of digital cameras and they can pack a huge amount of memory for very little cash;

Part 1: By MAURO GRASSI

WIB

Web server In a Box

we've seen them for as little as a fiver for eight gigs, and they're going down in price all the time! So, for not a lot more money, WIB can use an SD/MMC memory card which can be 16 or even 32 gigabytes – and that means it can store many thousands of pages of data, pictures or whatever, and all of these can be accessed as a website via the Internet.

Want to change the content? Well, you could upload new data remotely via the Internet or you could simply whip out the SD card, plug it into your computer and away you go. Or you could have several such SD cards, all with different web formats, presentations or whatever.

Maybe you would like to have a large picture library or whatever, accessible via the Internet. Of course, you could take the conventional web server approach, as outlined above. Or you could do it with our WIB.

In fact, the applications are unlimited. Think of an application involving a website and WIB can probably do it. For example, do you have a small business, perhaps selling goods via the Internet? Maybe WIB could house your website. We're sure there are lots of applications that have just been waiting for this simple hardware solution.

It only requires a modem or a modem/router to connect it to the Internet. And while it and the modem will need to be hooked up permanently, its energy use rates as flea power compared to a desktop computer or even a laptop when permanently powered up.

Furthermore, WIB can monitor the temperature or any other parameter (just connect a suitable sensor) and it can also be used to control four digital outputs and an RS232 serial port.

Down to earth

OK, we'll come clean. While we are very excited about this project, it didn't start out with such ambitious targets. The original intention was to produce a simple project which could monitor temperature or any other parameter in a home or remote location and display the resultant data on a website. At the same time, it could control a few outputs – perhaps switch on a heater or air-conditioner, or a few other prosaic functions.

But then we had the idea of using an SD/MMC memory card to store the

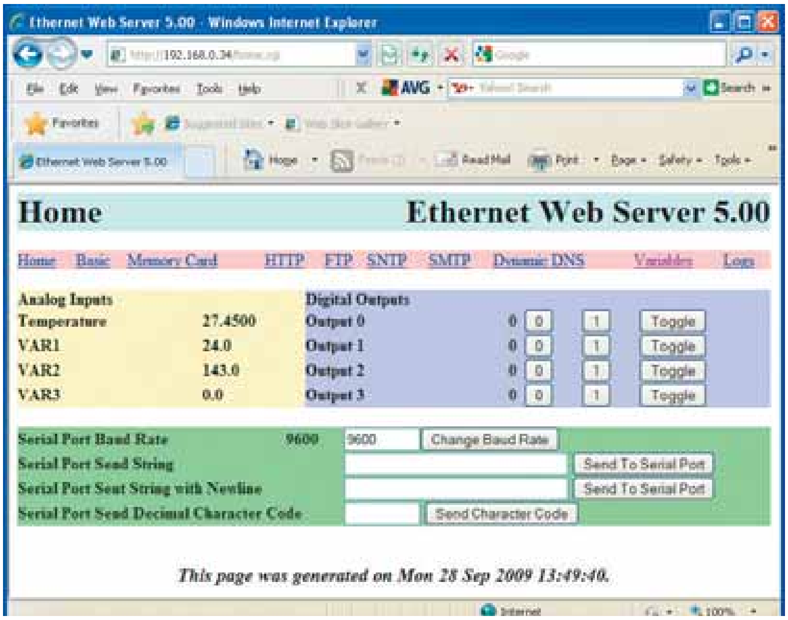


Fig.1: WIB's home page lets you configure the various functions, including the network, logging, email and FTP settings. It also allows you to read the analogue inputs (it's showing a temperature reading of 27.45°C here) and toggle the digital outputs. You can also send data strings to the serial port.

data and website. And it just grew from there.

Having thought of the memory card as the bulk memory for the project and realising just how cheap it was, the potential uses seemed to grow enormously. We are sure readers will come up with a host of different uses.

Let's also be realistic. We need to describe how this WIB project works, how it connects to the Internet and all the necessary know-how that this requires. There is a lot of jargon to be digested and understood, but when we have finished describing WIB in considerable detail, we are sure that you will see the potential.

Great opportunity

WIB presents a great learning opportunity for anyone interested in creating a personal website – it will be great for schools, too. For example, it could be teamed up with a weather station. You would be able to access it at any time via a mobile phone with a web browser.

WIB is not the complete server solution – it lacks some features like server side scripting and encryption, for example, although for most applications, this won't be a problem.

Its main advantage is that it is considerably simpler, cheaper and easier to set-up than a more powerful web server. In fact, if you have already gone through the set-up procedure for connecting a broadband modem to your computer, then this project should not be any more challenging.

Remote monitoring

In most basic applications, WIB lets you monitor up to four analogue inputs and control up to four digital outputs, as well as an RS-232 serial port.

WIB not only features an inbuilt web server, but includes inbuilt FTP and an email (SMTP (simple mail transfer protocol)) client as well. We will explain these terms as we go through.

The email client is used by the WIB to send emails to a nominated email address via an email server. Most ISPs (Internet service providers) provide an outgoing email server that the WIB can connect to, in order to send email.

The FTP (file transfer protocol) server allows you to store and retrieve files from a remote location, and also allows you to manage your website remotely. In addition, you can use it to back-up files off-site or transfer files (both text and images) to a remote location (eg, from the office to home).

The memory card can actually be an MMC, SD or SDHC card (up to 32GB).

The website can include dynamic content that's constantly updated with data from the four analogue inputs, and WIB can perform data logging of the inputs (as in a weather station) and save this information to a file.

The logged data can then be accessed either via the inbuilt FTP server or it can be automatically emailed to you at regular intervals. Just think – you will get emails from WIB – mind-boggling! The emails will be sent from the SMTP client within the WIB.

In practice, you can set the logging period (ie, how frequently the values are logged) and how many entries to keep in the log file. When this number is exceeded, the log file is automatically emailed to you and then cleared, ready for the next cycle. In this way, you could have daily reports of fluctuations in temperature or whatever emailed to your inbox.

The WIB also allows a limit to be set on a variable being monitored, and can notify you via email when the variable exceeds this limit. For example, you can set it to email you if the temperature rises above a preset level, so that you immediately know there is a problem.

Digital outputs

As stated earlier, you can also control four digital outputs and the serial RS-232 port using your browser (eg, Internet Explorer, Mozilla Firefox, Opera, Safari, or Google Chrome). These outputs can then be used to control external devices, either directly or via an interface board.

It's just a matter of toggling the digital outputs high or low by clicking on the 'Toggle' buttons – see Fig.1.

Network time

Another feature of WIB is an SNTP (simple network time protocol) client, which allows the correct time to be gathered automatically from the Internet. This time is used for logging purposes and can also be displayed in a dynamic web page.

A dynamic DNS (domain name system) client is also included. 'Domain Name' refers to any website name (such as **epemag.com.**). DNS enables the unit to keep track of its public IP (Internet protocol) address and notify a DDNS (dynamic domain name system) service if this address changes. By using this

service if this address changes. By using this service, you can log into the web server using a domain name rather than its IP address (an IP address is numerical and all devices connected to the Internet, such as your modem, have an IP address).

This is necessary, because the public IP address can change if your modem is turned off for some time, so you might not always know what it is.

Access and Ethernet

A nice aspect of this design is that it implements simple file permissions through HTTP (hypertext transfer protocol) authentication. This means that you can set a user name and password to access the whole website or just certain pages. You can also restrict access to certain files, based on the file extensions.

Finally, the WIB is highly configurable and can be set up to work with almost any Ethernet network. Did we mention Ethernet? This refers to the Ethernet cable and connectors on the back of your modem. Ethernet is a standard which is used to transmit data over a local network (for example, in an office) or to the Internet via a modem.

We will also be providing the source code for a website, so that you can easily modify the web server's settings if necessary, to suit your requirements.

Circuit details

Refer now to Fig.2 for the complete circuit details of the WIB. It's based on a dsPIC33FJ64GP802 microcontroller (IC1) and an ENC28J60 Ethernet controller (IC2), both from Microchip.

The Ethernet controller (IC2) provides the Ethernet link, including MAC (media access control) and the 10BaseT PHY (this means it runs at 10Mbits/second). It has 8KB transmit and receive dual port RAM buffers, hardware-assisted CRC (cyclic redundancy check – for error checking), automatic retransmit on collision (in case messages 'collide') and programmable packet (blocks of data) filtering.

Although Microchip makes microcontrollers with in-built Ethernet controllers, these are only available as surface-mount devices (SMDs). We wanted to avoid SMDs as far as possible, so we have specified an external controller (IC2) which comes in a conventional DIL package, as does the specified PIC microcontroller (IC1).

Main features

- **Highly customisable –** most settings, including IP address, port numbers and servers can be arbitrarily set
- **MMC/SD/SDHC memory card** for storage of web pages and other files (FAT/FAT32 file system)
- **HTTP (web) server** with changeable file permissions, dynamic pages, modified CGI commands and HTTP basic authentication
- **SMTP (email) client** for automatic email notifications with dynamic content.
- **FTP (file transfer protocol) server** for uploading website
- **Dynamic DNS client (DDNS)** to allow server to be contacted using a hostname
- **Network time (SNTP) client** to gather Internet time for logging
- **Four analogue inputs –** these can be: (a) monitored remotely using a web browser; (b) logged with periodic log files automatically emailed to a chosen email address; (c) assigned set limits, with automatic email notification when limits are exceeded
- **Four digital outputs** for controlling devices over the Internet
- **12 user-defined file extensions,** file permissions and file content for the HTTP server
- **A serial port output** that's controllable via the Internet
- **System logging** of special events.

The only SMD chip used in the whole project is the 8-pin MAC address chip (IC3), which comes in an SOIC package. And while IC2 does include MAC, we still need IC3 for providing the unique MAC address; more on this below.

In operation, the microcontroller (IC1) communicates with the Ethernet controller via an SPI (serial peripheral interface) bus. This SPI bus is also shared with the MAC address chip (IC3) and the memory card, which is accessed in SPI mode.

SPI communication requires four lines, and these are: $\overline{\text{CS}}$ (chip select – active low), SO (serial data output), SI (serial data input) and SCK (serial clock). You can share the bus among multiple devices by having multiple $\overline{\text{CS}}$ lines and ensuring that only one of these lines is active at any one time.

In this case, we use three $\overline{\text{CS}}$ lines: one for the Ethernet controller (RB8 of IC1), one for the memory card (RB2 of IC1) and one for the MAC address chip (RB6 of IC1). These are all controlled by the SPI master (IC1).

MAC address chip

The 25AA02E48 MAC address chip (IC3) is a 256-byte EEPROM with an SPI interface. It's main feature is that its last six bytes (bytes with addresses 0xFA to 0xFF) contain a unique, licensed MAC address.

An Ethernet device must have a unique MAC address in order to communicate in a network. By using this chip, we are ensuring that the MAC address for the web server is globally unique. These chips are intended for use in designs with small production runs, and save on the cost of licensing a range of MAC addresses from the relevant authority (IEEE).

Note that it is quite possible to overwrite the pre-programmed MAC address (it is an EEPROM chip after all). However, the chip has a write protect feature that can be enabled on a 64-byte block basis, and the last such block, which contains the MAC address, is protected by default.

In any case, the current version of the firmware does not write to the EEPROM and only reads from it. Pin 3 ($\overline{\text{WP}}$) is the write protect pin and this prevents writing to the EEPROM when low. In our case, however, it has been tied high to allow it to be written to if there is a future firmware upgrade.

Pin 7 ($\overline{\text{HLD}}$) is the hold pin, and this pauses the SPI interface logic inside IC3 if it is low. This feature is used in SPI bus sharing situations but has

Reading and writing data to the memory card

TO TRANSFER files from a PC to the memory card, you may need a low-cost SD/SDHC/MMC-card reader. The one shown at left is available from Jaycar (Cat No: XC-4756), while the unit at right reads all sorts of memory cards and is also available from Jaycar (Cat. XC-4849). They are simply connected to a PC via a USB port.

been disabled here by tying pin 7 high. Instead, we rely on the firmware in IC1 to provide proper arbitration between the three SPI devices.

Ethernet controller

The Ethernet controller chip (IC2) provides the physical and data link layer of the network. As already mentioned, it is a 10BaseT PHY (physical layer) running at 10Mbits/s and the data is transmitted on twisted-pair copper cables terminated in an RJ45 connector (the Ethernet socket).

PIC microcontroller IC1 writes to the Ethernet controller's registers via the SPI bus, which runs at 8MHz. Ethernet transmissions occur by Manchester encoding on the T+ (pin 17) and T– (pin 16) pins of IC2 via two 51Ω resistors. The resistor values are chosen to be close enough to match the characteristic impedance of the 10BaseT (Ethernet) cable, which is 100Ω. Similarly, reception occurs on the R+ (pin 13) and R– (pin 12) pins of IC2.

The Ethernet controller (IC2) requires some passive components to complete the physical Ethernet link (ie, to transmit and receive data), including two transformers. These transformers, plus four 75Ω resistors and a 1nF capacitor, are all part of RJ45 connector CON2 and provide electrical isolation from the network. In addition, the RJ45 connector contains two LEDs, one green and the other yellow.

According to the datasheet for the ENC28J60 (IC2), a 2.32kΩ resistor from pin 14 (R_{BIAS}) to ground is required to set the signal amplitude on the transmitting pair. This is made up using series 2kΩ and 330Ω resistors to give 2.33kΩ, which is near enough. IC2 also requires a 25MHz crystal to operate correctly, and this, together with its two 33pF loading capacitors, is connected to pins 23 and 24.

Outputs LEDA and LEDB of IC2 drive the two LEDs in the RJ45 connector. These outputs can be configured (using the registers in IC2) to light the connector LEDs under various conditions. In this case, we have chosen to drive the LEDs to conform to the usual convention, with the green LED indicating a valid Ethernet link and the yellow LED indicating data activity.

The remaining line to IC2 is the $\overline{RST}$ line (pin 10). This is the reset line, and is driven by the RB7 (pin 16) output of the microcontroller. It simply resets the internal logic of the Ethernet controller (IC2) when required.

Note that there are two other lines on IC2 which are unused: CKO and $\overline{INT}$.

CKO (pin 3) is a clock out line, and this delivers a square-wave whose frequency is related to IC2's system clock (in turn derived from the 25MHz crystal). This frequency can be configured via IC2's registers (it can be used to provide the clock for a microcontroller for example) but is not used here, as IC1 has its own crystal (X1). This was done to allow the microcontroller to run at its highest rated clock frequency.

The other unused line (pin 4) is the interrupt line. This can be used to interrupt the microcontroller under certain circumstances, but again, is not used here.

Memory card

As mentioned earlier, the memory card is accessed in SPI mode and this is done via the SD card socket (CON4). This allows microcontroller IC1 to read from and write to the memory card.

MMC/SD/SDHC cards can be accessed either in native mode or in SPI mode. The advantage of the SPI mode is that any off-the-shelf microcontroller that has an SPI peripheral can be used, making the hardware layer easy to implement. The interface with SPI is also simpler, but the penalty is slower transfer speeds. However, SPI speeds are quite adequate for serving web pages.

Inputs and outputs

Connector CON3 provides access to the analogue inputs and the digital outputs. The four analogue inputs are AN0 to AN3 of IC1 (pins 2 to 5) and these inputs are all protected using 10kΩ current-limiting resistors. An AD22103 temperature sensor IC (IC4) is shown connected to AN0 on Fig.2, but other types of sensors with a linear 0-3.3V output (or less) can also be used on the analogue inputs.

The digital outputs are at RB12 to RB15 (pins 23 to 26) of IC1 and toggle between 0V and 3.3V.

CON5 allows optional access to the serial (UART) port of IC1. Note that the levels are not true RS232 levels, but simply 3.3V CMOS levels.

LED indicators

Outputs RA4 and RB3 from IC1 are used to drive indicator LED1 and LED2. LED1 (green) lights whenever the memory card is accessed (ie, for both reads and writes), while LED2 (orange) is on during boot up until all initialisations have been completed. Once the web server has initialised, LED2 blinks on and off to indicate normal operation.

When LED2 is blinking, it shows that the cooperative multitasking main loop is executing, ie, no process is blocking operation or taking up

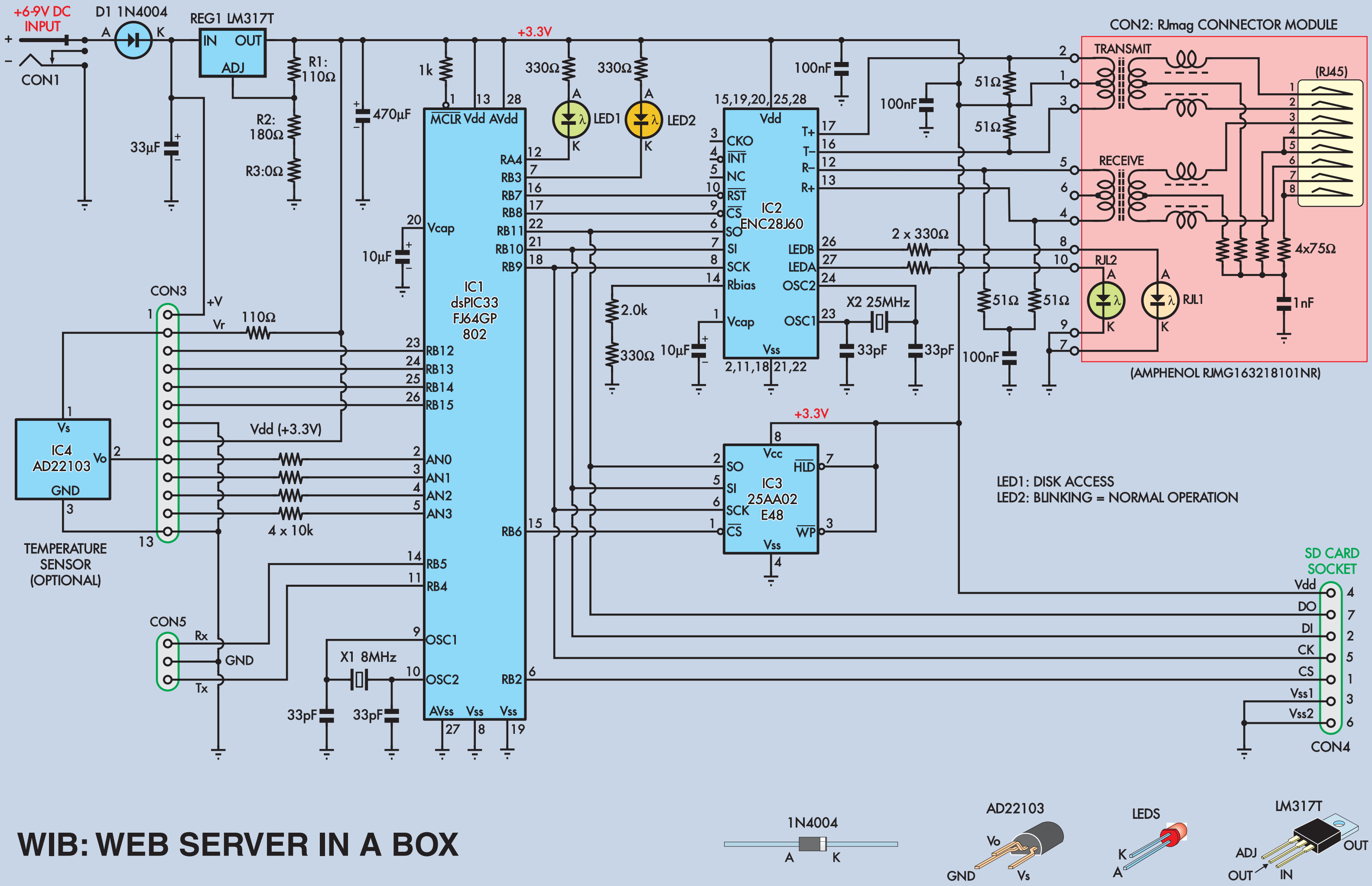


Fig.2: the circuit is based on a PIC microcontroller (IC1), an ENC28J60 Ethernet controller (IC2), a 25AA02E48 MAC address chip (IC3) and an external memory card. The PIC microcontroller interfaces to the memory card, reads the analogue inputs and controls the digital outputs at RB12 to RB15. It also drives the Ethernet controller (IC2), which in turn interfaces to the external network via an RJ45 connector. IC4 is an optional temperature sensor (AD22103) and is connected to one of the analogue inputs (AN0 in this case). Power comes from a 6V to 12V DC regulated plugpack supply.

All the jargon explained

DNS (domain name system): a system whereby domain names can be resolved to IP addresses.

DDNS (dynamic domain name system): a system whereby a fixed domain name can be associated with a dynamic IP address.

DHCP (dynamic host configuration protocol): a protocol that allows a DHCP server to assign an IP address to a DHCP client requesting it. The IP address is handed out on a limited time lease.

EEPROM (electrically erasable programmable read-only memory): a solid-state non-volatile memory chip that can be written to and erased.

Ethernet: a network standard for the physical and data link layer that determines how data is transmitted and received from a common medium.

FTP (file transfer protocol): a protocol used to transfer files across a network.

Gateway: a network node to which data traffic is directed. It relays this traffic in a way so as to reach its destination (using routing information).

HTTP (hypertext transfer protocol): a protocol commonly used to transfer web pages and content from a web server to a browser.

ICMP (Internet control message protocol): a protocol used to send status and error messages across the Internet. It is typically used for Ping (Packet Internet Groper).

IP (Internet protocol): a protocol used for transmitting data packets across a network, primarily used in the Internet.

IP address: each device sending or receiving IP packets must have a unique IP address, typically written as four decimal numbers in the range 0-255 (8-bit) and separated by dots. An example IP address is 192.168.0.34.

MAC (media access control): a protocol that implements the data link layer on an Ethernet network where nodes share a common medium.

MAC Address: each device sending or receiving Ethernet packets must have a unique MAC address. This is is a 6-byte address which is often written as six hexadecimal bytes joined by colons, for example: 00:04:A3:21:09:6C.

Manchester encoding: a self-clocking method of encoding binary data that relies on edge transitions.

Multi-tasking: the ability of a processor to run multiple tasks.

NAT (network address translation): a technique whereby a router can modify address and port information in packets to translate from one address space to another. Typically used in routers to share a single connection from your ISP among many devices in a home network.

Port forwarding: a technique used by routers to redirect traffic on a particular TCP or UDP port to a private IP address.

Protocol: a set of rules to allow network devices to communicate with each other.

SMTP (simple mail transfer protocol): a protocol used for sending email.

SNTP (simple network time protocol): a protocol used to receive time information from a remote time server. The time is returned as a number that represents the number of seconds that have elapsed since the epoch time which is set at 00:00 1 January 1970.

Static DHCP: a technique whereby a DHCP server can be made to assign a static IP address to a particular network device (by associating a static IP address with a MAC address).

Subnet Mask: this is in the style of an IP address and is used as a bitwise AND mask to determine whether an IP address is in the same network subnet.

TCP (transmission control protocol): a protocol for transmission of data that is connection oriented.

TCP/IP (transmission control protocol/Internet protocol): a family of protocols that allow network devices to communicate.

UART (universal asynchronous receiver/transmitter): a circuit used for serial communication between devices.

UDP (user datagram protocol): a protocol for transmission of data that is packet oriented.

inordinate processor time. At no time should the orange LED stop blinking during normal operation, otherwise data packets will be dropped.

Clock signals

Clock signals for the microcontroller are derived from an 8MHz crystal (X1). This is connected between pins 9 and 10 (OSC1 and OSC2), together with two 33pF capacitors which provide the correct loading. Note that IC1 runs at its maximum of 40MIPS (million instructions per second) – an internal PLL (phase-locked loop) stage is used to derive the system clock.

Power for the CPU inside IC1 is derived from the main 3.3V rail using an internal 2.5V regulator. This requires a 10µF tantalum bypass capacitor on pin 20. Similarly, a 10µF bypass capacitor is fitted to pin 1 of the Ethernet controller (IC2).

Note that IC1's reset pin ($\overline{\text{MCLR}}$, pin 1) is pulled permanently high by a 1kΩ resistor, and so is not used here. Instead, IC1 is reset by its internal power-on reset logic.

Power supply

Power for the circuit is derived from a 6V to 9V DC plugpack, and this is applied via reverse-polarity-protection diode D1. The resulting DC rail is then filtered using a 33µF capacitor and fed to an LM317T adjustable 3-terminal regulator (REG1) to derive a +3.3V rail. This +3.3V rail then powers IC1 to IC3 and the memory card.

REG1's output voltage is set by the divider network on its OUT and ADJ terminals according to the following formula:

$$V_{OUT} = 1.25V \times (1 + (R2/R1))$$

By using a 110Ω resistor for R1 and a 180Ω resistor for R2, we get an output voltage that's very close to 3.3V.

In practice though, the 1.25V reference in the regulator can vary anywhere between 1.2V and 1.3V, due to manufacturing tolerances. For this reason, provision is made on the PC board for an additional resistor (R3) in series with R2 so that you can adjust the output voltage if necessary. In most cases, you won't need to do this and a wire link is used for R3 instead (more on this later).

The supply rail at the output of diode D1 is also fed to a terminal on

CON1, so that it can be used to power external devices if necessary. In addition, the +3.3V rail is fed to two other terminals on CON3, in one case via a 110Ω current-limiting resistor. The current-limited +3.3V rail (Vr) is used to power the AD22103 temperature sensor (IC4).

The 110Ω current-limiting resistor is necessary because the temperature sensor is connected to the circuit via a stereo jack socket. In operation, it prevents the supply rail from being shorted to ground each time the stereo jack is plugged into its socket (the jack's tip touches the socket's ring as it is inserted). The 110Ω resistor protects against short circuits and doesn't interfere with the operation of the temperature sensor itself, as the latter's current draw is negligible.

Parts List – WIB (Web server In a Box)

1 PC board, code 830, available from the *EPE PCB Service*, size 123mm × 74mm
2 28-pin 0.3-inch IC sockets
1 3-way pin socket, 2.54mm pitch
8 M3 × 6mm machine screws
4 M3 × 15mm tapped nylon spacers
1 250mm-length of 0.7mm tinned copper for links
1 2.5mm PC-mount male DC power connector (Jaycar PS-0520
1 TO-220 mini finned heatsink (Jaycar HH-8502)
1 8MHz crystal (X1)
1 25MHz crystal (X2)
1 plastic instrument case, 95mm × 158mm × 47mm (Jaycar HB-5922)
1 SD surface-mount memory card socket (Jaycar PS-0024)
1 Ethernet RJ45 Connector with Magnetics, Amphenol RJMG163218101NR (Farnell 135-7435)
3 3-way screw terminal blocks (5.04mm pitch)
2 2-way screw terminal blocks (5.04mm pitch)
1 6V to 9V DC 300mA plugpack (Jaycar MP-3145)
1 3.5mm stereo jack (optional)
1 3.5mm stereo socket, chassis mount (optional)

Semiconductors
1 dsPIC33FJ64GP802-I/SP programmed microcontroller (IC1)
1 ENC28J60 Ethernet controller (IC2)
1 25AA02E48 serial EEPROM, with MAC address (IC3)
1 AD22103 temp. sensor (IC4) (optional) (Farnell 143-8415)
1 1N4004 silicon diode (D1)
1 LM317T adjustable 3-terminal regulator (REG1)
1 3mm green LED (LED1)
1 3mm orange LED (LED2)

Capacitors
1 470µF 16V electrolytic
1 33µF 16V electrolytic
2 10µF tantalum
3 100nF monolithic
4 33pF ceramic

Resistors (0.25W, 1%)

4 10kΩ	1 180Ω
1 2kΩ	2 110Ω
1 1kΩ	4 51Ω
5 330Ω	

Firmware overview

OK, so that's the hardware side of things and it's all fairly straightforward. Most of the features are implemented in the firmware, so let's now take a closer look at this.

The firmware uses the freely available TCP/IP stack from Microchip. We've customised it and also implemented some missing features in the minimal stack.

The stack is based on a cooperative multi-tasking model (ie, a lot of tasks run concurrently) and this has been retained. The main program is an infinite loop, with finite state machines used to keep track of stack processes that need attention.

The other major addition is the memory card driver and the FAT/FAT32 file system that resides on top of that. The WIB recognises the FAT/FAT32 file system, which means that you should be able to read the memory card using any Windows, Mac or Linux box (and a card reader).

The modules used in the TCP/IP stack include HTTP, FTP, ICMP, SNTP, SMTP, DNS and Dynamic DNS. Only the limited amount of program memory on the microcontroller prevented us from including further modules, such as a DHCP client to automatically pick up an IP address.

Because there's no DHCP client, the web server is assigned a static IP address and this is also necessary for port forwarding. However, a DHCP client working in conjunction with static DHCP could have been useful for incorporating the web server into an automatically configured network.

In any case, the DHCP server in your router must be configured to reserve a static IP address for the WIB. We'll tell you how to do that next month.

MMC/SD/SDHC memory cards

Either an MMC, SD or SDHC memory card can be used in the web server. MMC (MultiMedia Card) and SD (Secure Digital) cards use FLASH memory technology and are available in capacities up to 2GB. SDHC cards are essentially high-capacity SD cards, and are available in sizes ranging from 4GB to 32GB.

All three types of card can be used in this project. Note that while all three types look alike, MMC cards have only seven metal contacts, whereas SD cards have nine.

MiniSD and MicroSD cards can also be used. These are essentially SD cards, but are smaller. You will need an external adaptor in order to plug them into the SD card socket used in the web server.

Software

The software program files for the *Web server In a Box* will be available from the *EPE* website at: **www.epemag.com**.

Construction

Building the WIB is easy with all parts mounted on a single-sided PC board, code 830, and is available from the *EPE PCB Service*. This board measures 123mm × 74mm and is housed inside a plastic utility case.

The only slightly tricky bit is the surface-mount IC (IC3) which is mounted on the copper side of the PC board. However, this SOIC device has only eight pins and the pin spacing is around 1.27mm, so it's not too difficult to hand solder.

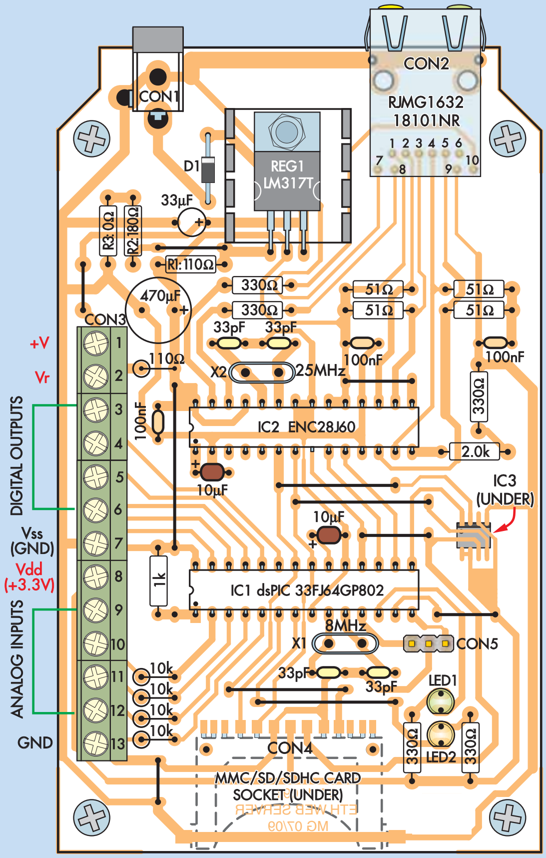
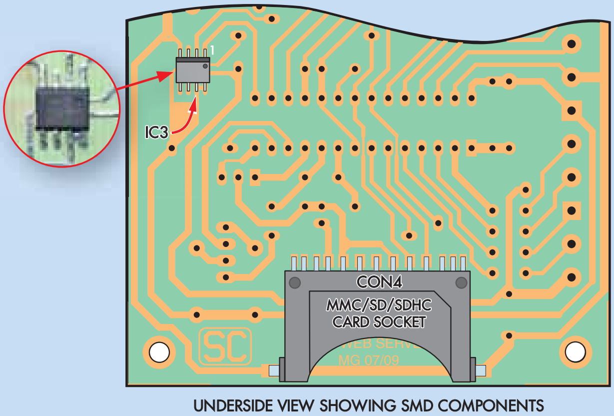


Fig.3: install the parts on the PC board as shown on this layout diagram. Make sure all polarised parts are correctly oriented and leave IC1 and IC2 out until after the power supply has been checked – see text.

Fig.4 (below): this diagram and the accompanying photos show how IC3 and the SD memory card socket are installed on the track side of the PC board. Note the orientation of the IC and don't forget to solder the two tabs of the memory card socket adjacent to the edge of the board.



The component layout on the PC board is shown in Fig.3 and Fig.4. However, before beginning the assembly, it's a good idea to carefully inspect the board for etching defects (eg, shorted copper tracks and hairline cracks). Such faults are rare, but checking now can save a lot a hassle later on.

Check also that corner cutouts have been made at the CON1 and CON2 end of the board, so that it will later clear the mounting posts inside the case. If not, you will have to make the cutouts yourself using a fine-toothed hacksaw and a small, flat file.

Having done that, the first job is to install the 11 wire links – see Fig.3. These can be cut from a length of 0.7mm tinned copper wire. If necessary, you can first straighten the link wire by clamping one end in a vice and then stretching it slightly by pulling on the other end using a pair of pliers.

Once the links are in, the next step is to install the resistors. These can go in either way, and some are mounted end-on to save board space. Table 1 shows the resistor colour codes but you should also check each one with a DMM before installing it.

You can either use a zero-ohm resistor for R3, or you can install a wire link.

Diode D1 and crystals X1 and X2 are next on the list. Note the orientation of D1 and don't get the two crystals mixed up. The 8MHz crystal is used for X1, while the 25MHz crystal is X2.

Now for the LM317T regulator (REG1). This mounts horizontally on the board and is fitted with a TO-220 finned heatsink for cooling. It's installed by first bending its leads down by 90° about 5mm from its body. It's then secured in place, along with its heatsink, using an M3 × 6mm machine screw, flat washer and nut and its leads soldered.

Note: do not solder REG1's leads before bolting it down. If you do, the PC tracks could crack as the assembly is tightened down.

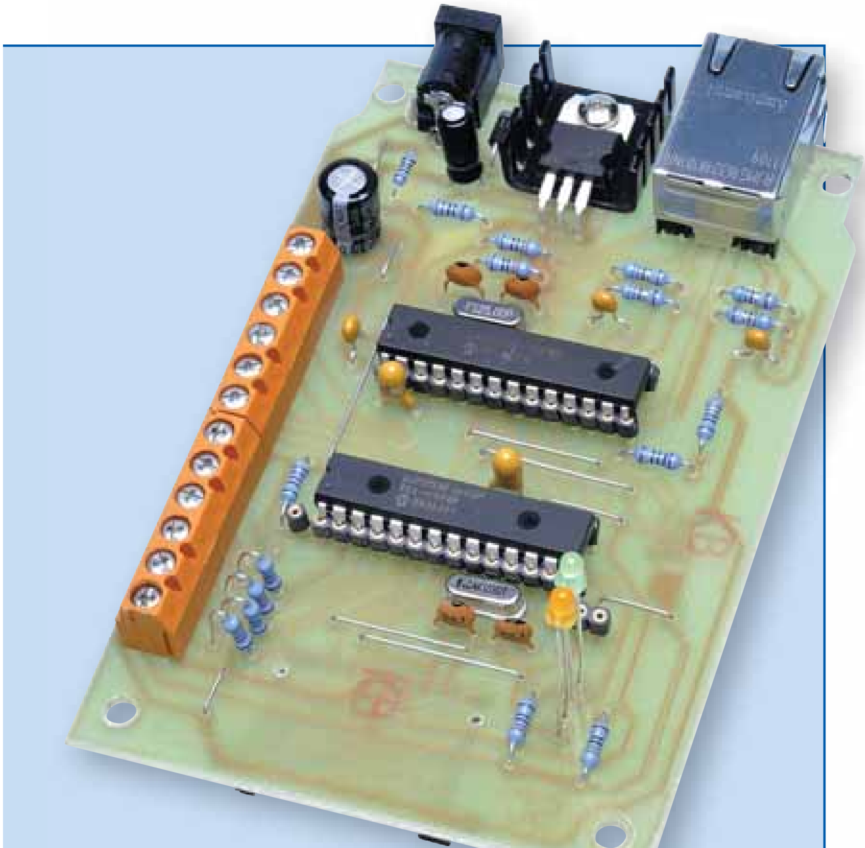
The two 28-pin machine IC sockets can now be installed. Be sure to orient these with their notched ends as shown on Fig.3. If you are unable to obtain 28-pin 0.3-inch sockets, you can use pin header strips instead. Alternatively you can cut 28-pin 0.6-inch sockets in half or you can use two 14-pin sockets mounted end-to-end.

Do not install the two ICs in their sockets yet. That step comes later.

Follow these parts with the capacitors, starting with the 33pF ceramic and 100nF monolithic types. The two 10µF tantalum capacitors can then be installed, followed by the 33µF and 470µF electrolytics. Note that the tantalum and electrolytic capacitors are all polarised, so make sure they go in the right way around – see Fig.3.

Connectors

The DC socket (CON1), the RJ45 connector (CON2) and the 3-way pin socket (CON5) can now go in. Make sure that these parts are sitting flush against the PC board before soldering their pins. In addition, take care when



This view shows the completed PC board. Note that there are a few differences between this prototype board and the final version shown in Fig.3, especially around CON1, CON2 and REG1.

soldering the RJ45 connector, as some of its pins are quite close together and it's easy to get solder shorts. **Don't forget to solder the two pins near the edge of the PC board, as these help secure the socket in position.**

The 13-way screw terminal block (CON3) is made up using three 3-way blocks and two 2-way blocks. These should all be dovetailed together and mounted as a single unit, with the access holes facing the edge of the board.

The board assembly (minus the three ICs and the SD card socket) can now be completed by soldering in the two LEDs. These should both be mounted at full lead length, with their bodies 25mm above the board so that they will later protrude through the lid of the case. Use the green LED for LED1 and the orange LED for LED2, and make sure they are oriented correctly.

A 25mm-high cardboard spacer can be used to set their height. Just slide this spacer between each LED's leads and push the LED down onto it before soldering it in place.

Initial tests

You will need a 6V to 9V DC 300mA (or greater) regulated plugpack fitted with a 2.5mm connector to power this project.

With the three ICs out of the circuit, apply power and use a DMM (digital multimeter) to measure the voltage between the OUT terminal of REG1 and GND. It should measure close to 3.3V and this same voltage should also appear at the Vdd (3.3V) terminal of CON3.

If you don't get the correct reading, switch off immediately and check for wiring errors. In particular, check the resistor values on the OUT and ADJ terminals of REG1 if the reading is high or low. Alternatively, if you don't get any voltage at all, check the supply polarity and D1's orientation.

Trimming the 3.3V rail

The accuracy of the +3.3V rail is important because some MMC/SD/SDHC cards operate over quite a narrow voltage range. The firmware checks that the inserted card operates at 3.3V, so it is crucial that REG1's output be close to +3.3V.

If the 3.3V rail is more than 3.4V or less than 3.2V, you will need to change one or both of the values for R2 and R3. For example, if the voltage is around +3.17V, you will need to install a 10Ω resistor for R3 and this should increase the rail so that it is close to +3.3V.

Alternatively, if the output voltage is +3.41V, you should change the value of R2 to 160Ω and R3 to 10Ω (giving a total value for R2 + R3 = 170Ω), or you could use 150Ω for R2 and 22Ω for R3. Again, this should bring the voltage from REG1 pretty close to +3.3V.

Once the supply voltage is correct, switch off and install IC1 and IC2

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	4	10kΩ	brown black orange brown	brown black black red brown
❏	1	1kΩ	brown black red brown	brown black black brown brown
❏	4	330Ω	orange orange brown brown	orange orange black black brown
❏	1	180Ω	brown grey brown brown	brown grey black black brown
❏	2	110Ω	brown brown brown brown	brown brown black black brown
❏	4	51Ω	green brown black brown	green brown black gold brown

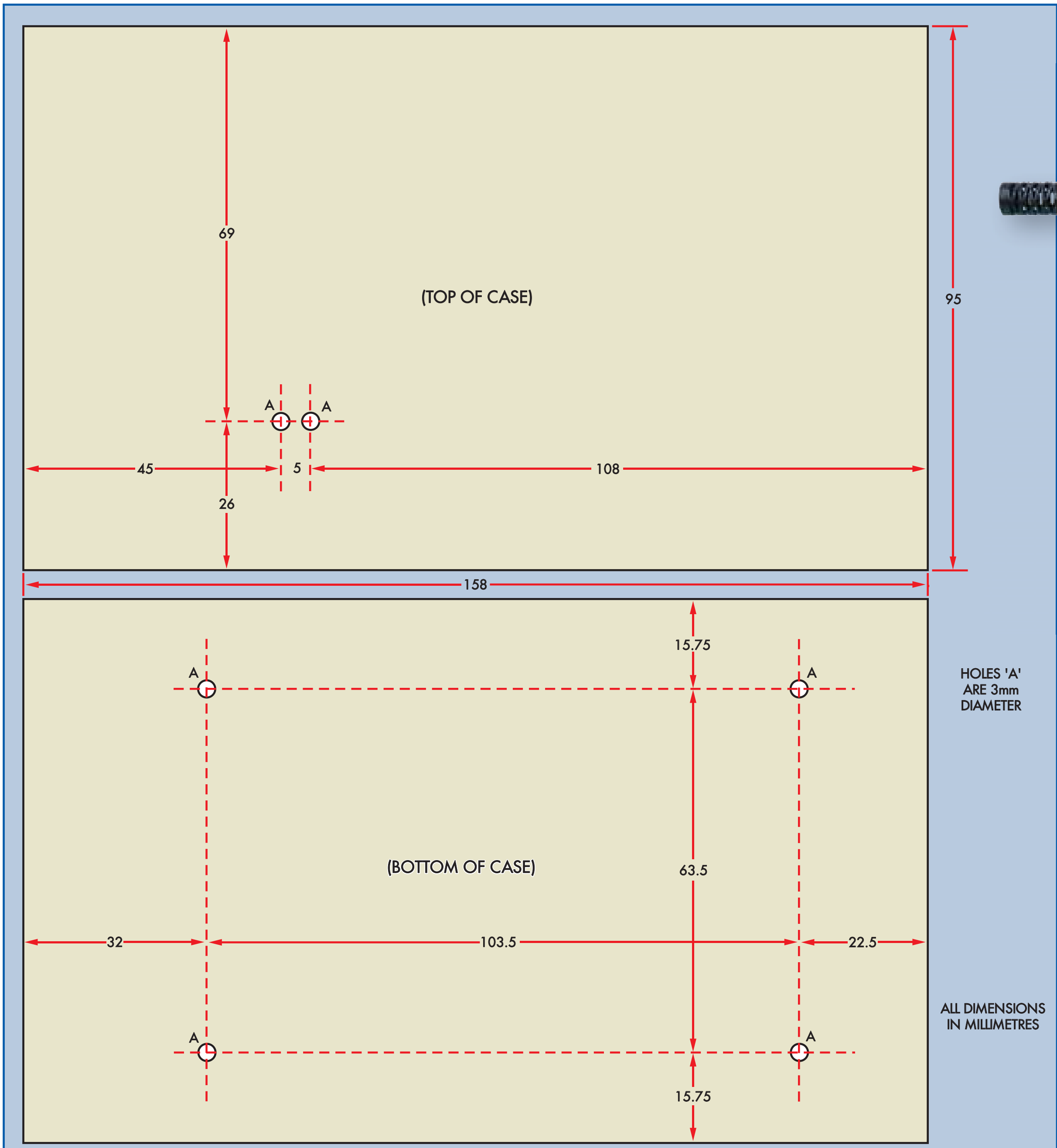


Fig.5: here are the drilling details for the top and bottom case sections. All the holes are drilled to 3mm diameter.

into their sockets. Make sure they are oriented correctly (see Fig.3) and don't get them mixed up.

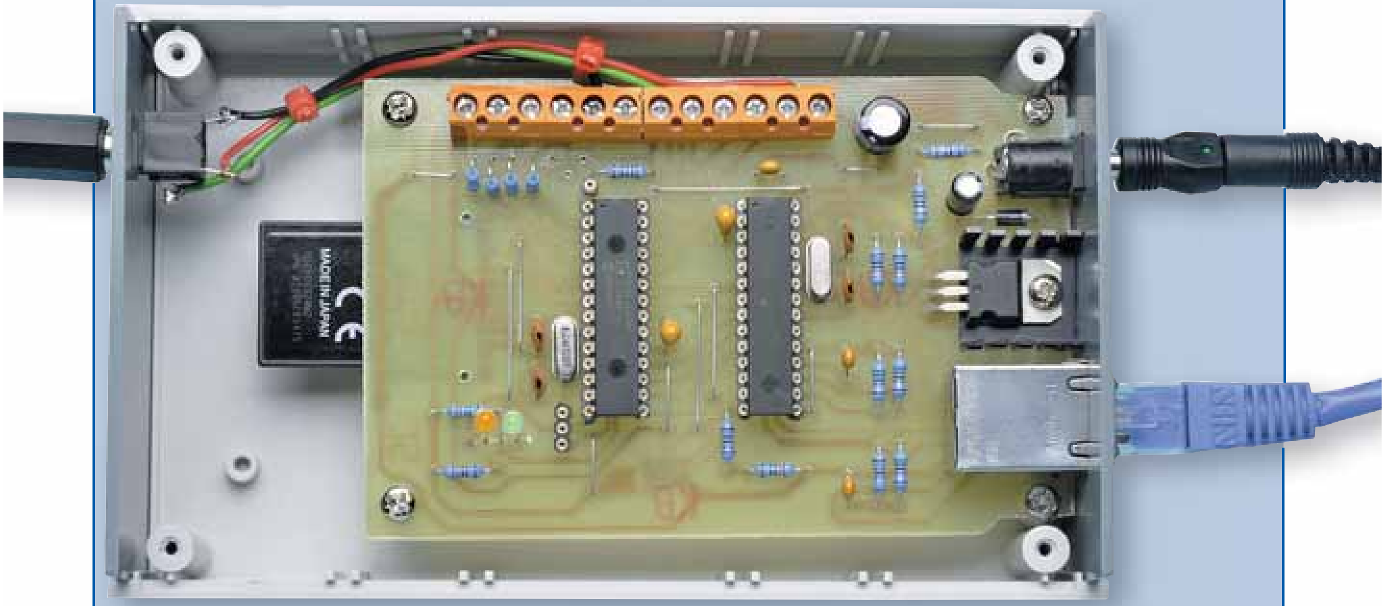
Installing the SMD parts

The SMD parts (ie, IC3 and SD card socket CON4) mount on the copper side of the board, as shown in Fig.4. You will need a fine-tipped soldering iron, some fine solder, some solder wick and (preferably) a magnifying lamp.

Begin by carefully aligning the IC with it solder pads, making sure that it is oriented as shown (ie, pin 1 at upper right, as indicated by the dot in its body). If you like, you can hold it in position using self-closing tweezers.

That done, lightly tack solder pin 1, then remove the tweezers and inspect the IC under a magnifying glass to make sure it is in the correct

The PC board fits neatly inside a standard plastic utility case (note: the final board is longer than the version shown here). The memory card can be removed or installed by sliding the adjacent end panel out of its slot.



position. The remaining pins can then be soldered, starting with the diagonally opposite pin (pin 5). Don't forget to add a little more solder to pin 1 if necessary to complete the job.

Do this job as quickly as possibe, so as not to overheat and damage the tracks on the PC board. Once you have finished, inspect the soldering under a magnifying glass again. If any of the pins are shorted by solder (other than pins 7 and 8), then you can remove the excess solder using the solder wick.

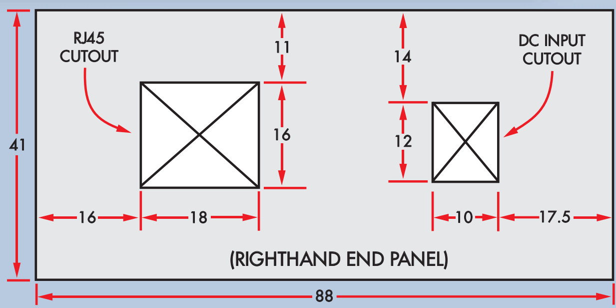


Fig.6: here's how to make the cutouts in the righthand end panel for the RJ45 socket and the DC power socket.

Memory card socket

While you are on the copper side of the PC board, you can solder in the memory card socket as well. It is an SMD socket, so you must place it over its pads and solder in one of the pins first to anchor it in position. Once that is done, check that it is correctly aligned before soldering the remaining pins.

Note that there are two mounting pads towards the front of the socket. These must also be soldered.

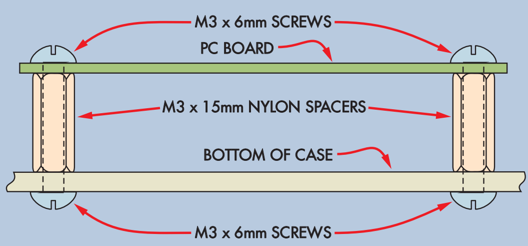


Fig.7: the PC board is mounted in the case on four M3 × 15mm tapped nylon spacers and secured using M3 × 6mm screws.

Final assembly

The prototype was housed in a plastic instrument case measuring 95mm × 158mm × 47mm (Jaycar HB-5922). This is marked out and drilled as shown in Fig.5 and Fig.6. You need to drill two 3mm holes in the lid for the LEDs and four 3mm mounting holes in the base (Fig.5). In addition, you have to make two square cut-outs in one of the end panels for the DC socket and RJ45 connector (Fig.6).

Each of these cut-outs can be made by drilling a series of small holes around the inside perimeter, then knocking out the centre piece and cleaning up the edges with a flat file.

Installing the temperature sensor

The optional AD22103 ratiometric temperature sensor (IC4) is installed by mounting it inside a 3.5mm stereo plug – see Fig.8. Its +Vs lead is connected to the ring terminal of the stereo plug, its Vo lead to the sleeve and its GND lead to the plug's tip.

This plugs into a matching stereo jack socket mounted on the end of the case, and this is wired back to CON3 on the PC board.

As shown in Fig.8, the +Vs supply lead connects to the +Vr terminal (terminal 2) of CON3, the GND lead connects to terminal 7 of CON3, and the Vo (sensor voltage output) lead connects to one of the four analogue inputs of CON3 (either terminal 9, 10, 11 or 12).

The temperature sensor is mounted outside the case to ensure that it is unaffected by the heat generated by other parts. This heat comes mainly from the LM317T voltage regulator, but the ICs also contribute. Mounting the sensor outside the case ensures an accurate measurement of the room temperature.

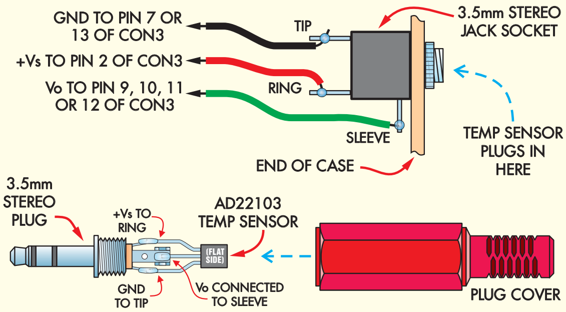


Fig.8: connect the AD22103 temperature sensor to the 3.5mm stereo plug as shown here. You can use a DMM to identify the tip and ring terminals.

The AD22103 temperature sensor is mounted inside a 3.5mm stereo jack – see Fig.8.

If you are installing the specified temperature sensor, then you will also need to drill a 6mm hole in the second end panel (see Fig.8 and photos).

Deburr all holes using an oversize drill, then secure four M3 × 15mm nylon spacers to the base using M3 × 6mm screws. The PC board can then be dropped into place along with the right-hand end panel and secured using another four M3 × 6mm screws, as shown in Fig.7.

Installing the memory card

You will need a suitable MMC, SD or SDHC memory card to use with the WIB. This should be formatted with a FAT/FAT32 file system before plugging it into the memory card socket (see photo). With the ICs installed and power applied, the orange LED should blink on and off approximately twice a second.

That completes the construction of the WIB. However, before using the device, you need to copy the necessary files to the memory card and interface the server to your network. This will involve entering a few settings like the Gateway address, IP Address and Subnet mask, turning on port forwarding in your router and activating a dynamic DNS (DDNS) service.

We'll explain how that's all done in Part 2 – next month!

Security disclaimer

THIS SERVER relies on a username and password for security. This username and password combination must be used to access the FTP server (to modify the file system) and to access private web pages through HTTP (ie, using a web browser).

This is the main security mechanism to prevent unauthorised access from a remote location over the Internet. All settings should also be protected by the username/password combination – see next month's article for more details.

Note, however, that given the correct username and password combination, a user could log into the server and change all the settings by accessing the file system on the memory card through an FTP client. In addition, they could change the password and username combination to lock others out of the system.

If that ever happens, the remedy is to write to the card using a PC and a memory card reader and define a new username/password pair. Of course, this assumes you have physical access to the memory card.

This web server cannot be considered highly secure because it is prone to DoS (denial of service) attacks, as are most web servers. On a positive note, HTTP authentication occurs server side and therefore no transmission of a coded version of the username and password occurs (although it is possible to intercept the HTTP headers that contain the correct username and password – they are not encrypted but encoded using base 64).

There are also a limited number of commands, no server side script execution and the microcontroller uses a (modified) Harvard architecture, making the server somewhat more secure than most.

By JOHN CLARKE

Using a wideband O_2 sensor in your car – Part 2

Construction and installation details

Last month, we introduced our new Wideband Oxygen Sensor Controller and described the circuit. This month, we show you how to build it and provide the test and installation details.

BUILDING the *Wideband Oxygen Sensor Controller* is straightforward. All the parts, except for the wideband oxygen sensor, are mounted on a PC board, code 829, measuring 112mm × 87mm. This is housed in a diecast box measuring 119mm × 94mm × 34mm.

An 8-pin circular multipole panel plug connector is used to provide the interface to the external wideband sensor. This sensor is mounted on the exhaust (either directly or via an adaptor pipe) and connects to the controller via a 7-way extension cable.

In addition, the controller is fed with power via leads which enter through a cable gland, and these wires terminate into an on-board screw terminal block. The 3-wire connection to the optional Wideband Display Unit also passes through this cable gland.

Circuit board assembly

Refer to Fig.13 for the component layout on the PC board. Begin construction by checking the board for any defects, such as shorted tracks or breaks in the copper.

Check that the corners have been shaped to clear the internal corner pillars of the specified box by test fitting it in place. Similarly, check that the board has had rectangular sections removed from either side so that it will later clear the nuts used to secure the multipole connector and the cable gland. The shape required is indicated using thin tracks on the underside of the PC board.

Now start the parts assembly. Insert the wire links and resistors first, taking care to place each in its correct place. The 0.1Ω 5W resistor runs cold and can be mounted flush against the PC board.

Next, install the diodes, Zener diodes and the ICs, but don't install IC1 (the PIC micro). Instead, install a socket at its location. Make sure that this socket and the other ICs are all oriented correctly (ie, notched ends towards the top of the PC board).

Follow with the capacitors, taking care to install the electrolytic types with the polarity indicated. That done, install REG1, REG2 and Q1. These parts are all mounted flat against the PC board, so you will have to bend their leads down through 90° to get them to fit. This involves bending down the two outer leads of each device about 8mm from its body, while the inner lead is bent down about 6mm.

Secure the metal tabs of these devices to the board using an M3 × 6mm screw and nut *before* soldering their leads to the PC board. Don't solder the

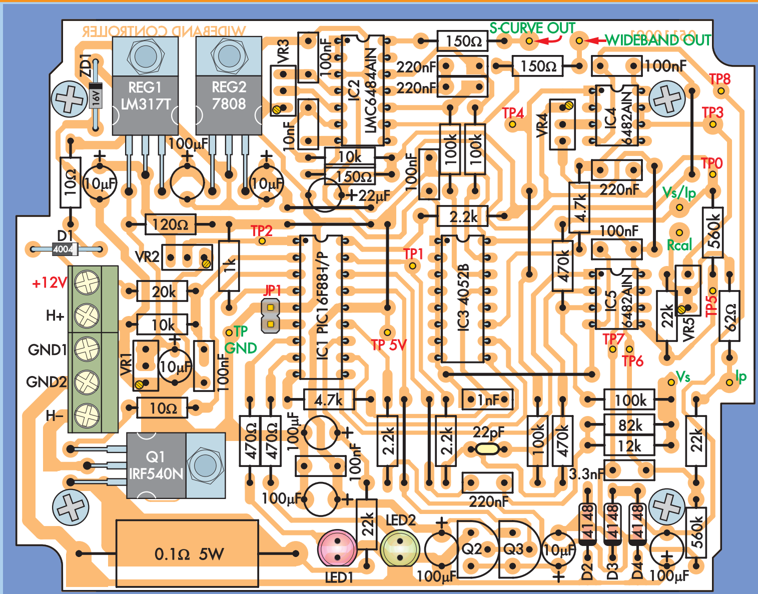


Fig.13: install the parts on the PC board as shown here. Use PC stakes at all the test points (TP0 to TP8) and make sure that the semiconductors and electrolytic capacitors are all oriented correctly.

The completed PC board is mounted inside a diecast metal case on plastic stand-offs.

leads first, otherwise you could crack the PC board copper track pattern as the screw is tightened down. Be sure to install the correct part at each location.

Transistors Q2 and Q3 can go in next. **Be sure to use a BC327 for Q2 and a BC337 for Q3. Do not get these two transistors mixed up.** Once they are in, install the 2-way pin header for JP1, then install PC stakes at the external wiring positions (see Fig.14).

LED 1 and LED 2 are next on the list. These must be installed with the top of each LED exactly 24mm above the PC board. You can set their height by pushing each LED down onto a 19mm cardboard spacer that's slid between its leads. In each case, the anode (longer lead) must go towards the top of the PC board.

The three trimpots (VR1 to VR4) can now go in. Be sure to use the correct value at each location and orient each one with its adjusting screw as shown on Fig.13 (this ensures that the voltages at their wipers increase with clockwise rotation).

Note that these trimpots may be marked with a code other than the actual resistance value in ohms; ie, the 500Ω trimpot may be coded as 501, the 5kΩ trimpots may be coded as 502 and the 1kΩ trimpot may be coded as 102.

Finally, complete the PC board assembly by installing the 3-way and 2-way screw terminal blocks. These must be dovetailed together to form a 5-way block before installing them on the PC board. Make sure that the wiring access holes face towards the edge of the PC board.

Boxing up

The PC board is mounted inside the diecast box on M3 × 6mm tapped nylon spacers, and secured using M3 × 4mm screws. Before doing this though, you will need to drill all the necessary holes.

First, position the PC board inside the base and use it as a template to mark out its four corner mounting holes. That done, remove the board and drill these holes to 3mm diameter. Deburr them using an oversize drill.

Next, you need to drill holes in the ends of the box to accept the cable gland and the 8-pin circular connector (see photo). The location and diameters of these holes is indicated on Fig.14. They are best made by using a small pilot drill to begin with, then carefully enlarging each to its correct size using a tapered reamer.

Finally, you will need to drill a 3mm hole in the front side of the case to anchor the earth solder lug.

Interwiring

Once all the holes have been drilled, secure the board in position, then run the wiring as shown in Fig.14. Note that you **must** use 7.5A rated wire (as marked on the diagram) for the

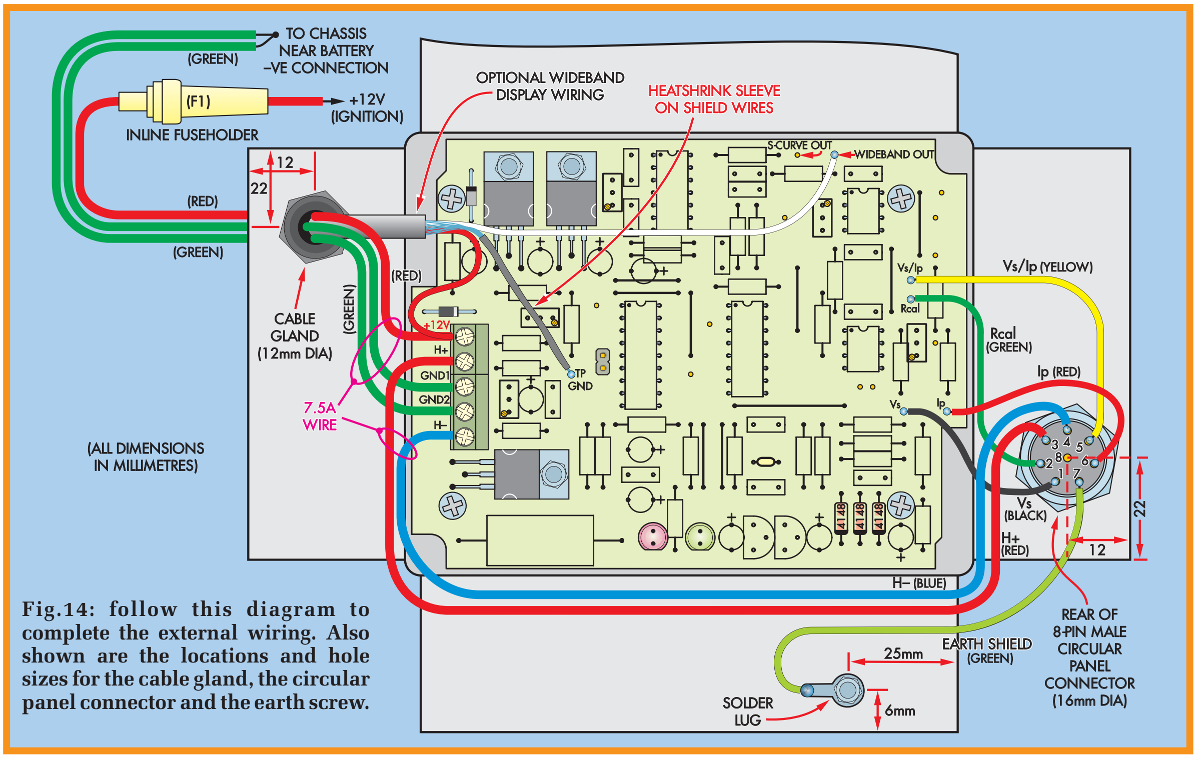


Fig.14: follow this diagram to complete the external wiring. Also shown are the locations and hole sizes for the cable gland, the circular panel connector and the earth screw.

12V supply, ground and heater wires, because these carry heavy currents.

The 8-pole circular panel connector is wired by first connecting the sensor wires to the PC stakes on the PC board and the heater wires to the screw terminal block. The wires are then fed through the nut and washer for the circular connector and then through the mounting hole before soldering them to the connector itself.

Note that each soldered pin is covered with heatshrink tubing to avoid shorts and to prevent the wires from breaking. This means you will have to slide a length of heatshrink over each wire before soldering it to the connector. After soldering, the heatshrink is pushed over the connection and shrunk down with a hot-air gun.

Similarly, the leads for the power supply should be fed through the cable gland before connecting them to the screw terminal block. If you are using the wideband and S-curve outputs, these wires also go through the gland. For the Wideband Display Unit, the 0V rail can be obtained from the TP GND pin, while the +12V supply can be picked up from the +12V terminal on the 5-way terminal block.

Note that the +12V supply lead requires an in-line fuseholder and 5A fuse. This supply is obtained from the vehicle's ignition circuit. **Note that, because of the currents involved in the heater circuit, two earth wires MUST be used, as shown in Fig.14.** These connect together at the vehicle's chassis.

For temporary use, the cigarette lighter socket can be used to provide power via a lighter plug connector.

Sensor extension cable

The sensor extension cable is wired as shown in Fig.15. Make sure that the wiring is correct and use heavy-duty cable for the H+ and H– leads.

The wiring is shown from the back of each connector, so be sure to follow this carefully. Note that the 6-pin connector includes wire-sealing glands, and these are placed over each lead before it is attached to the 2.8mm female crimp spade terminals.

That completes the assembly. Now for the setting-up procedure.

Setting up and testing

It's best to initially configure the Wideband Controller to measure the oxygen content of the air. That way, the controller can be tested with a known gas, ie, one that comprises 20.9% oxygen in fresh air.

This test requires the installation of two extra 560kΩ resistors in parallel with the 560kΩ resistors associated with IC5b (ie, one across the existing resistor to pin 5 and the other added across the existing resistor between pins 6 and 7). The Vs/Ip and offset voltage set by VR4 is also different compared to the normal set-up for measuring exhaust gas.

If you prefer to skip the above step in the setting-up procedure, leave the extra resistors out and simply connect your multimeter between TP3 and Rcal. Set the meter to read ohms and adjust trimpot VR5 for a reading of 311Ω. That done, skip directly to the 'Engine exhaust readings setup' procedure and ignore the instruction to remove the 560kΩ resistors between TP0 and TP5 and between TP6 and TP7.

Oxygen concentration settings

If you do intend to first measure the oxygen content of the air, just follow this step-by-step procedure:

Step 1: solder one 560kΩ resistor between TP0 and TP5 and a second 560kΩ resistor between TP6 and TP7.

Above: this view shows the completed extension cable with the sensor attached.

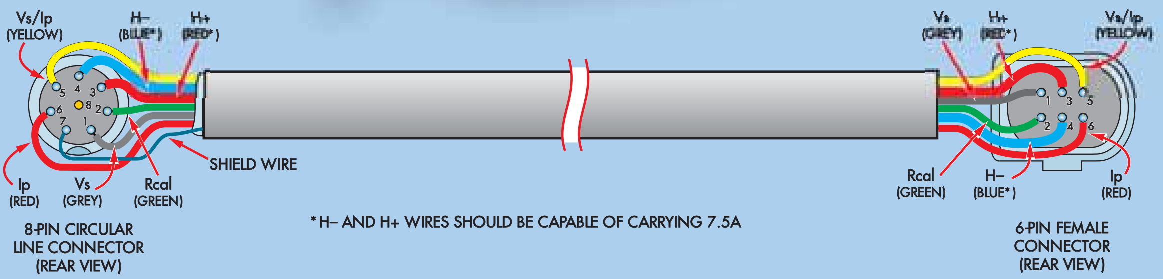


Fig.15: the wiring details for the sensor extension cable. Make sure that the wiring is correct, otherwise the sensor could be damaged. Also, be sure to use heavy-duty cable for the heater H+ and H– leads, and note that the 6-pin female connector at right is shown from the rear.

Step 2: remove the jumper plug from JP1 and connect a multimeter between TP3 and Rcal. Set the multimeter to read ohms.

Step 3: adjust VR5 for a reading of 311Ω.

Step 4: check that IC1 is still out of its socket and that the sensor is unplugged, then apply power (12V) to the circuit. Monitor the voltage between TP 5V and TP GND and adjust VR1 for a reading of 5.00V.

Step 5: monitor the voltage between Vs/Ip and TP GND and adjust VR3 for a reading of 2.00V.

Step 6: monitor the voltage between TP4 and TP GND and adjust VR4 for a reading of 2.343V.

This view shows female 6-pin connector (left) at the end of the extension cable and the matching male plug that comes fitted to the sensor (right).

Mounting the oxygen sensor

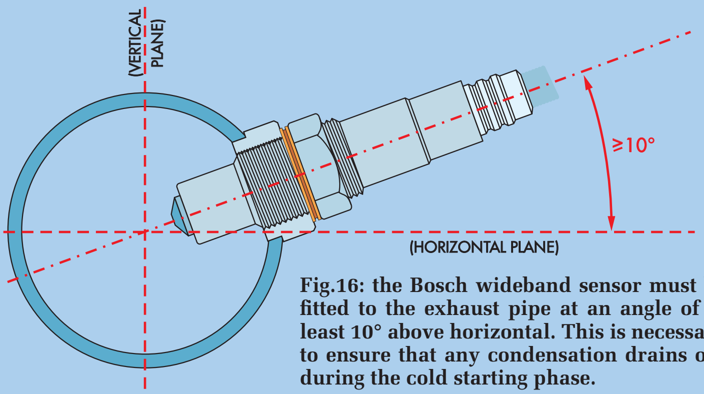


Fig.16: the Bosch wideband sensor must be fitted to the exhaust pipe at an angle of at least 10° above horizontal. This is necessary to ensure that any condensation drains out during the cold starting phase.

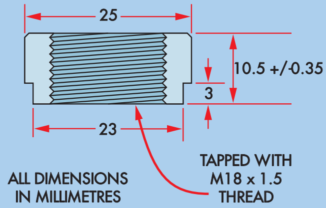


Fig.17: this diagram shows the dimensions of the threaded boss that's used to attach the sensor. It must be made of stainless steel and should cover the sensor's thread completely.

The tightening torque is from 40 to 60Nm.

Step 7: switch off and install IC1 in its socket (watch its orientation). Reapply power and check that pin 8 of IC4 is at about 8V and that TP8 is at about –2.5V. If the latter voltage is positive, check the orientation of diodes D2 to D4 and check the placement of Q2 and Q3. Check the orientation of the 10µF and 100µF capacitors as well.

Step 8: now you are ready to test the operation with the oxygen sensor connected. Switch off and connect the sensor to the Wideband Controller. Before switching on, check that there is resistance between H+ and H–. It should be about 3.2Ω at 20°C.

Note that the sensor will get hot and so the plastic protective cap should be removed and the sensor placed on a surface that can withstand 200°C. Glass cookware (eg, Pyrex) is ideal. Note also that the tip of the heater can become very hot.

Step 9: apply power and check that the Heat LED (LED1, red) lights. If it doesn't, check its orientation. Check that both the Wideband output and the S-curve output are at 0V.

After about 20-seconds, the Heat LED should start flashing and the Data LED should light. The flashing Heat LED indicates that the sensor has reached operating temperature, while the lit Data LED indicates that the Wideband Controller is measuring the oxygen content in the air and that the reading is available at the wideband output.

The wideband output voltage will be proportional to the oxygen content. A 2.09V reading corresponds to 20.9%.

Step 10: check that the voltage at the wideband output is close to 2.09V. It should be within 1% of this value if you are at sea level and the measured air is not in a confined space. At higher altitudes, the value will be lower because the lower air pressure affects the reading.

In practice, the air pressure drops by approximately 10hPa for every 100m above sea level, starting from a standard pressure of 1013.25hPa. However, this pressure decrease rate does not apply for altitudes above 2000m where the rate becomes non-linear. And, of course, weather conditions also affect air pressure.

For more detail, refer to the *Ip versus Pressure* graph (Fig.11) published last month. Typically, the reading will be 4% less at an altitude of 1000m above sea level. Since the oxygen concentration versus Ip current is almost linear, the graph can also be interpreted as the change in oxygen concentration reading with pressure. The oxygen concentration in percent is the reading from the Wideband Controller.

Step 11: if the reading is nowhere near the expected value, check the resistor values on the PC board. Although adjusting the value of the 62Ω resistor can recalibrate the reading, this should not be necessary and we have not provided for trimming this resistor.

Step 12: this step adjusts trimpot VR5 to give the best operating conditions for the Wideband Controller and to obtain the highest resolution available. To do this, measure the voltage at TP3 and adjust VR5 so that the voltage is at about 4.8V.

This setting now suits the particular sensor connected. If you change the sensor, this adjustment will have to be repeated. Alternatively, you can

How to remove the narrowband sensor

It is highly unlikely that an open-ended 22mm spanner will be sufficient to remove the original oxygen sensor. Instead, it will be so tight that the nut will refuse to budge and will simply start to 'round off' under the spanner.

Basically, you will require a special oxygen sensor removal tool. This comprises a 22mm socket that has a slit along one side to allow for the oxygen sensor wires to protrude.

Even with this tool, we found that the oxygen sensor was difficult to remove. Initially, no amount of force would budge it as it was seized solidly in place. In the end, we used 'Loctite Freeze and Release Lubricant' (Part No. FAR IDH1024403) to help free it. This 'shock cools' and penetrates and lubricates the screw threads and this allowed us to eventually remove the sensor.

Note that special high-temperature grease must be used on the screw threads if you refit the existing sensor. A new sensor (such as the Bosch wideband sensor) will be supplied with this grease already applied to the thread.

just leave VR5 set at 311Ω to suit all Bosch LSU4.2 sensors.

Step 13: check the various operating voltages. The voltage between Vs and TP GND should be 2.450V, while the voltage between Vs/Ip and Vs should be 450mV. The voltage between TP1 and TP GND should be 2.5V.

There may be small variations here as the controller continually adjusts the current to maintain these voltages. If you have an oscilloscope, you will be able to see the 177mVp-p square wave imposed on the Vs voltage used for sensor impedance measurement.

Engine exhaust readings set-up

Having checked that the Wideband Controller accurately measures the O_2 content in air, you now have to readjust it to give accurate engine exhaust measurements. Here's what to do:

Step 1: switch off and remove the extra 560kΩ resistors between TP0 and TP5 and between TP6 and TP7.

Step 2: disconnect the sensor, then reapply power and adjust VR3 for a reading of 3.30V between the Vs/Ip terminal and TP GND.

Step 3: adjust VR4 for a reading of 3.92V between TP4 and TP GND, then check the voltage on TP1. This should be 0.385V with the sensor disconnected. This voltage can be adjusted by tweaking VR4, but the TP4 reading should still be at or very close to 3.92V.

Step 4: disconnect power and reconnect the sensor. Apply power again and check that the Heat LED is fully lit. Once this LED flashes, the Data LED will also flash at the same rate, indicating that the gas under measurement (air) is too lean for the lambda range of up to 1.84 (air has a lambda of 207).

Step 5: check that the wideband output is close to 5V and that the S-curve output is close to 0V.

Step 6: fit jumper JP1 to the 2-pin header. The Wideband Controller is now ready to measure exhaust gas.

Sensor installation

As mentioned in Part 1, the Bosch LSU4.2 wideband sensor can be installed in the exhaust pipe using a suitable threaded boss. This should be as close to the engine as possible.

Note, however, that the exhaust gas temperature under all engine-operating conditions at the sensor position must be less than 850°C. In general, installing the wideband sensor in the same position as the existing narrow-band sensor will be OK.

The following points should also be taken into consideration:

1) The sensor must not be mounted in the exhaust manifold of a turbo-charged engine. Instead, it must be installed *after* the turbocharger.
2) The exhaust pipe section prior to the sensor should not contain any pockets, projections, protrusions, edges or flex-tubes, to avoid the accumulation of condensation water. Locating the sensor on a 'downhill slope' of the pipe is recommended.
3) Make sure that the front hole of the sensor's double protection tube does not point directly into the exhaust gas stream. Instead, mount the sensor perpendicular to the exhaust stream so that it can constantly monitor fresh exhaust gas.
4) Never switch on the sensor heating until the engine starts. **This means that jumper JP1 must be installed to ensure heating does not begin until 13V has been measured on the battery supply. Check that this jumper is installed.**
5) The sensor must be mounted so that it is inclined at least 10° from horizontal (electrical connection upwards) – see Fig.16. This is necessary to prevent liquid collecting between the sensor housing and the element during the cold start phase.
6) The sensor receives reference air through the connection cable. For this reason, DO NOT use cleaning fluids or grease at the sensor plug connection.
7) The recommended material to use for the threaded boss in the exhaust pipe is temperature-resistant stainless steel to the following standards: DIN 174401.4301 or 1.4303, SAE 30304 or 30305 (US). Fig.17 shows the thread boss dimensions. **Note that the sensor thread must be covered completely.**
8) The use of high-temperature-resistant grease on the screw-in thread of the boss is recommended. The tightening torque is from 40 to 60 Nm.
9) The sensor must be protected if an underseal such as wax or tar or spray oil is applied to the vehicle.

A Bosch LSU4.2 wideband sensor is used with the Wideband Controller. Note that other wideband sensors are NOT suitable for use with this controller.

10) The sensor must not be exposed to strong mechanical shocks (for eample, during installation). If it is, the element could crack without visible damage to the housing.
11) Both the sensor and its connecting cable should be positioned to avoid damage due to stones or other debris thrown up by the wheels.
12) Do not expose the sensor to water drips from the air-conditioner or from sources such as windscreen run-off during rain or when using the windscreen washer. The resulting thermal stress could damage the sensor.

Fast preheat

Provided the sensor is correctly installed in the exhaust pipe and is rapidly heated by the exhaust, it can be preheated more quickly by starting at a higher effective heater voltage.

To do this, the code for the Wideband Controller requires a small change. This as at line 706 and involves removing the semicolon (;) from the beginning of line 706 – ie, from in front of 'btfsc PORTB,0'. The file then needs to be saved, reassembled and used to reprogram the PIC micro (IC1).

This change is only recommended if all mounting requirements are met. In addition, jumper JP1 will need to be installed for the fast start preheat to take effect.

The Wideband Controller assumes an initial temperature of –40°C for pre-heating. This ensures that the sensor is not heated too rapidly for any initial temperature that's likely to be encountered.

Using the S-curve output

As mentioned, the S-curve output from the Wideband Controller can be used to replace the existing narrowband

Tailpipe sensing

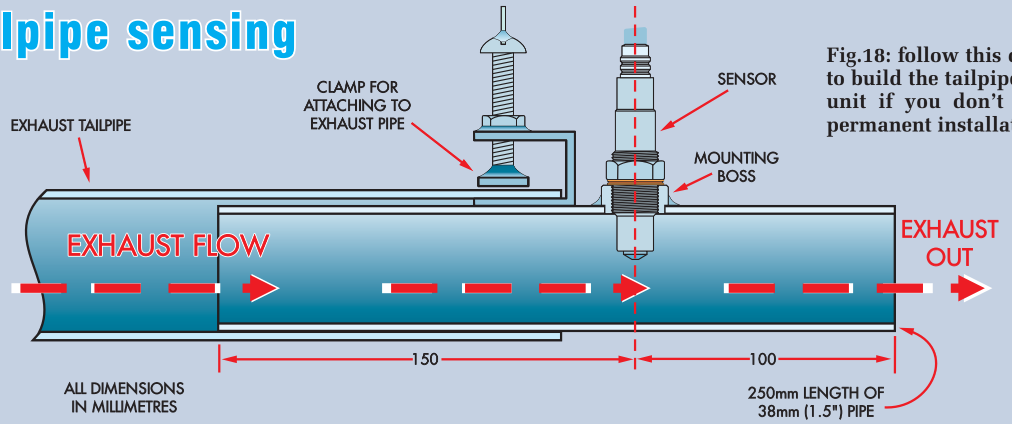


Fig.18: follow this diagram to build the tailpipe sensor unit if you don't want a permanent installation.

IF YOU don't wish to install the wideband sensor permanently, an alternative is to mount it in a tailpipe extension. This tailpipe extension can then be slid over the end of the tailpipe and clamped in position – see Fig.18.

Note, however, that any readings obtained using this method will be affected by the catalytic converter and so won't be as accurate. That's because the catalytic converter reacts with the exhaust gas and changes the oxygen content. In addition, some catalytic converters include an air bleed to feed oxygen into the exhaust to allow full catalytic operation with rich gases.

Of course, this won't be a problem in older cars that don't have a catalytic converter. However, the sensor must be placed so that the exhaust is not diluted by air. Note also that exposing the sensor's leads to exhaust gas may alter the reference air composition of the sensor and give false readings.

Fig.18 should be followed quite closely if you intend mounting the sensor in a tailpipe extension. By using the dimensions shown, the sampled exhaust gas is taken sufficiently upstream from the end of the tailpipe to prevent dilution with outside air.

The pipe and clamp materials can be made of steel or brass, but do use a stainless-steel boss for mounting the sensor.

signal. However, the vehicle must be currently using a zirconia-type narrowband oxygen sensor. If the vehicle already has a wideband sensor, then this sensor should not be replaced with the S-curve signal.

A less common type of narrowband lambda sensor has a ceramic element made of titanium dioxide. This type does not generate a voltage, but instead changes its resistance according to the oxygen concentration. Once again, this type cannot be simulated using the S-curve signal.

The Wideband Controller mates with the Wideband Oxygen Sensor Display unit described in the *EPE* October 2011 issue.

Identifying the sensor leads

In order to replace the existing sensor with the S-curve output from the Wideband Controller, you first need to identify the leads running from the sensor to the ECU.

Basically, there are four narrowband sensor variations:

1) If the sensor has one lead this will be the signal wire and the sensor body will be ground.
2) If the sensor has two leads, one will be the signal lead and the other will either be a +12V heater supply or the signal common. For a heated sensor, the body will be a common ground for both the signal and heater circuits.
3) A 3-wire sensor has Heater+ (H+), Heater– (H–) and sensor signal leads, with the body as the signal ground.
4) The 4-wire sensor is similar to the 3-wire sensor, but with an extra ground lead for the signal ground.

In each case, the leads are quite easy to identify but first a word of warning. **Do not measure the narrowband sensor impedance with a multimeter. The reason for this is that the current produced by the meter for resistance measurements will damage the sensor.**

Note also that the maximum loading for the sensor is ±1µA. **This means that to measure the voltage produced by a narrowband sensor, the meter must have an input impedance higher than 1MΩ.** Digital multimeters generally have an input impedance much higher than 1MΩ and so they can be used to measure the sensor's output voltage. However, the input impedance of an analogue meter may not be high enough.

The first step in identifying the leads is to set your DMM to DC volts (eg, 20V), then connect the negative lead of the DMM to chassis. That done, it's a matter of starting the engine and probing the sensor's leads with the DMM's positive lead (a pin can be used to pierce the wire insulation, but seal any holes with silicone afterwards to prevent corrosion). The sensor's H+ lead will be at +12V, while its signal voltage lead will be at about 450mV.

Frequently Asked Questions

Q: Can a wideband sensor directly replace a narrowband sensor?
A: No, a wideband sensor must be used in conjunction with a Wideband Controller. If the Wideband Controller has a simulated narrowband output, then this can usually be connected to the ECU's oxygen sensor input instead of the narrowband sensor.

Q: I have heard that narrowband oxygen sensor (S-curve) simulators are not recognised as a valid sensor by the ECU, which records a diagnostics fault code. Will the narrowband output of the Wideband Controller be recognised correctly as a valid sensor?
A: Yes, usually it will. Narrowband sensor simulators usually comprise an oscillator that delivers a voltage centred about 450mV, with a sinusoidal variation of about 50mV above and below 450mV. However, these simulators oscillate continuously regardless of mixture and do not respond in the usual manner to mixture changes (ie, where a rich mixture cause the sensor output to rise above the 450mV stoichiometric point and a lean mixture cause it to fall below this point).

By contrast, the Wideband Controller's S-curve output simulates the response of a narrowband sensor, and it bases its output voltage on the actual mixture readings. So a lean mixture will cause the narrowband output to fall and a rich mixture will cause the narrowband output to rise above the 450mV stoichiometric point. Consequently, the ECU will recognise the signal as valid because it responds to mixture variations correctly.

Q: Can I use a different wideband sensor with the Wideband Controller?
A: No, only the Bosch LSU4.2 is suitable.

Q: When the wideband sensor is installed in the exhaust pipe are there any special precautions to prevent sensor damage?
A: Yes, first, the controller must not be switched on until after the engine has started in order to remove any condensation within the sensor before it is electrically heated. In addition, the sensor must be mounted more than 10° from horizontal to allow moisture to run out. The sensor must also be installed where the exhaust gas heats the sensor quickly, but where it does not go above 850°C.

Q: Can a wideband sensor be left installed in the exhaust pipe without a controller?
A: Yes, but only for a short duration. Otherwise you should remove the unused sensor and plug the exhaust hole if the sensor is not connected to a controller.

Q: Can the sensor and controller be used with a 24V supply?
A: No, the sensor has not been designed to cater for 24V operation and using it at this voltage would result in excessive heater element current.

Q: Can the sensor run from a 9V (216) battery?
A: No, the heater current is too high for a 216 type 9V battery. Also, a 9V supply may not be sufficient for the heater to reach the required operating temperature.

Q: I want to monitor the Heat and Data LEDs inside the car. Can these LEDs be external to the wideband controller and connected to the controller using long wires?
A: Yes they can.

Q: If I unplug or plug-in the wideband sensor to the controller while the controller is still powered will it damage the sensor?
A: There is a possibility the sensor will be damaged, due to reverse Ip current. It's also possible that the ceramic material may crack due to incorrect heating up from cold.

Q: What is the life of the sensor?
A: Typically 10,000 hours or 160,000km if handled and installed correctly.

Q: How long after the controller is switched on before the air/fuel readings are available?
A: Less than 22 seconds with a 20°C gas temperature.

Once these two leads have been identified, switch off the engine and unplug the sensor. The H– terminal can now be identified – it's the one that gives a resistance reading of typically 5Ω (and usually less than 10Ω) to the previously identified H+ terminal. **(Warning: do not connect the meter probe to the previously identified signal terminal when making resistance measurements).**

The ground terminal is the one remaining.

With Bosch sensors, two white leads are used for the heater, while a black lead is used for the signal and a grey lead is used for sensor ground. However, this does not apply in all cases.

In some cars, the ECU will check that the sensor is connected and produce an error code if it detects that anything is amiss. In most cases, however, the S-curve signal from the Wideband Controller will be accepted as valid, but there are exceptions.

First, the ECU may check the sensor's impedance to determine if it is sufficiently heated (ie, when its impedance falls below a particular value). However, the impedance the ECU will measure at the Wideband Controller's S-curve output will be 150Ω, and this may be incorrect for some sensors. For the Bosch LSM11 narrowband sensor, the impedance is less than 250Ω when heated and so the 150Ω impedance for the S-curve output should be satisfactory.

Other sensors may differ, however, and so the 150Ω output resistor may have to be changed to prevent an error code.

No provision has been made to vary the S-curve output impedance to simulate the heating of the sensor over time (ie, from a high value when cold to around 150Ω when hot). Usually, for a *cold* engine start, the ECU will wait until the engine is warm (as indicated by the temperature sensor in the cooling system) before readings from the oxygen sensor take place. By this time, the sensor will also be warm, with the S-curve output responding as it should to mixture variations and having a low impedance as expected by the ECU.

Conversely, the sensor will already be hot for a *warm* engine start.

If the ECU expects the S-curve output impedance to be high at engine start-up, then a timer such as the Flexitimer (*EPE*, August 2010) can be used. This can be set to provide an open circuit connection between the S-curve output and the ECU for about 20 seconds after engine start, at which point the timer's relay contacts close to make the connection.

Heater fault indications

Some ECUs will indicate a fault if the heater leads to the oxygen sensor are

Parts List – Wideband Oxygen Sensor Controller

1 PC board, code 829, available from the *EPE PCB Service*, size 112mm × 87mm
1 diecast metal box, 119mm × 94mm × 34mm (Jaycar Cat HB-5067)
1 8-pin circular multipole panel plug connector (microphone type)
1 3AG in-line fuseholder
1 5A 3AG fuse (F1)
1 DIP18 IC socket
1 2-way PC mount screw terminals (5.04mm spacing)
1 3-way PC mount screw terminals (5.04mm spacing)
12 M3 x 4mm screws
4 M3 nuts
4 M3 x 6mm tapped nylon spacers (do NOT use metal types)
1 3-6.5mm cable gland
17 PC stakes
1 2-way pin header with 2.54mm spacing
1 jumper for pin header
1 solder lug
1 50mm length of yellow medium duty (2A) hookup wire
1 50mm length of red medium duty (2A) hookup wire
1 50mm length of black medium duty (2A) hookup wire
1 100mm length of green medium duty (2A) hookup wire
1 150mm length of light blue **heavy duty (7.5A)** hookup wire
1 4m length of green **heavy duty (7.5A)** hookup wire
1 2m length of red **heavy duty (7.5A)** hookup wire
1 250mm length of 0.7mm tinned copper wire (or 9 zero ohm links)
1 140mm length of 3mm heatshrink tubing (or 20mm yellow, 40mm red, 40mm black, 40mm green)

Semiconductors
1 PIC16F88-I/P programmed microcontroller (IC1)
1 LMC6484AIN quad CMOS op amp (IC2)
1 CD4052BCN 1-to-4 CMOS analogue multiplexer (IC3)
2 LMC6482AIN dual CMOS op amps (IC4,IC5)
1 LM317T adjustable regulator (REG1)
1 7808 8V regulator (REG2)
1 IRF540N 100V 33A *N-channel* MOSFET (Q1)
1 BC327 *PNP* transistor (Q2)
1 BC337 *NPN* transistor (Q3)
1 3mm red LED (LED1)
1 3mm green LED (LED2)
1 16V 1W Zener diode (ZD1)
1 1N4004 1A diode (D1)
3 1N4148 signal diodes (D2 to D4)

Capacitors
5 100µF 16V PC electrolytic
1 22µF 16V PC electrolytic
4 10µF 16V PC electrolytic
4 220nF MKT polyester
6 100nF MKT polyester
1 10nF MKT polyester
1 3.3nF MKT polyester
1 1nF MKT polyester
1 22pF ceramic

Trimpots
1 500Ω multiturm trimpot (3296W type) (Code 501) (VR1)
3 5kΩ multiturm trimpot (3296W type) (Code 502) (VR2-VR4)
2 1kΩ multiturm trimpot (3296W type) (Code 102) (VR5)

Resistors (0.25W, 1%)

4 560kΩ*	3 2.2kΩ
2 470kΩ	1 1kΩ
4 100kΩ	2 470Ω
1 82kΩ	3 150Ω
3 22kΩ	1 120Ω
1 20kΩ	1 62Ω
1 12kΩ	2 10Ω
2 10kΩ	1 0.1Ω 5W
2 4.7kΩ	

*(Two used for % oxygen in air readings)

Sensor Parts
1 Bosch LSU4.2 broadband oxygen sensor
Available from: TechEdge (http://wbo2.com/lsu/sensors.htm part # [07200])
Bosch. Part # 0 258 007 200
Audi/VW Part # 021-906-262-B.

disconnected. In this case, you will have to keep the original heater connection to the old oxygen sensor and mount it in a convenient place (eg, against the firewall). Just make sure that the heated sensor cannot be accidentally touched, as it can run very hot.

Alternatively, you can make up a resistance box that has the same nominal resistance as the sensor's heater element when hot. This should go in a diecast case and you will need to use resistors rated for the power.

The power rating is calculated by assuming a 14.8V maximum supply and a 50% derating. For example, if the heater resistance is 12Ω, then 14.8V^2 divided by 12Ω gives 18.25W. In practice, a 40W resistor would thus be required.

A 12Ω 40W heater resistance could be simulated by connecting four 10W 47Ω resistors in parallel.

Sensor response rate

Another ECU check may involve the way the sensor responds to mixture changes in the exhaust gas. The ECU will expect the sensor output to be higher than 450mV for rich mixtures and less than 450mV for lean mixtures, and the sensor's response rate may be tested.

For optimal set-up of the delay, the S-curve output from the Wideband Controller can be set to match the response of the original narrowband sensor. This adjustment is made using VR2 and can be as fast as the overall wideband response of <250ms when VR2 is adjusted for 0V on TP2. This can be increased up to an extra 1.2s – when VR2 is set to that, TP2 is at 5V, with shorter delays in between.

For example, a setting of 2.5V will increase the overall wideband response delay by 600ms (ie, to 250 + 600 = 850ms).

The correct setting for your vehicle can be easily determined if you have an oscilloscope. To do the test, make sure the original narrowband sensor is installed and connect the scope probe to the sensor's output signal. Alternatively, an OBD (on-board diagnostics) scan tool that shows live or real-time parameter data can be used to monitor the sensor voltage if this feature is supported on your vehicle.

When the engine is warm and idling, the sensor reading should oscillate above and below 450mV at a rate dependent on the sensor's response rate and the ECU. By using the oscilloscope, the frequency of oscillation and the voltage can be directly measured.

A typical narrowband sensor response is shown in Fig.19.

1 6-pin female connector for the sensor, including 6 x 2.8mm female crimp spade terminals plus 6 end seals
Available from: Techedge (http://wbo2.com/cable/lsuconns.htm part # [CNK7200])
Or VW Part # 1J0-973-733 for the plastic shell only, type FEP FKG6-2,8/2FEP42122200.

1 8-pin circular multipole line socket
Available from:TechEdge (http://wbo2.com/cable/connkit.htm part # [P8PIN]
Or www.farnell.com.au cat #804-1563

1 6-way sheathed and shielded lead with 2x7.5A wires for heater.
Available from: Techedge (http://wbo2.com/cable/default.htm part # [DIY26CBL] for 2.6m long or part # [DIY40CBL] 4m long. Both parts include the 8-pin circular multi-pole line socket

1 8-pin circular multipole panel plug connector (microphone)
Available from: Techedge (http://wbo2.com/cable/connkit.htm part # [S8PIN]
Or www.farnell.com.au cat #804-1709

Now replace the narrowband sensor with the wideband sensor and connect the S-curve output from the Wideband Controller to the sensor+ signal input of the ECU. That done, adjust VR2 so that the response appears to be similar to that from the narrowband sensor. Note that adjustments to VR2 can take up to five seconds to have any effect, so take it slowly.

If you don't have an oscilloscope, monitor the narrowband sensor output using a DMM and then try to match the response when the Wideband Controller's S-curve output is substituted. However, this method will not be very accurate.

Alternatively, you may prefer not to bother trying to match the response time. In that case, set VR2 so that TP2 is at 1.25V. This will increase the normal Wideband Controller response by about 300ms (ie, to about 550ms), which should suit most vehicles.

By the way, oxygen sensors do have a slower response as they age. This means that a faster response from the Wideband Controller can be used to simulate the narrowband sensor's output when it was new.

Finally, if the S-curve simulation proves unsuccessful, either because the engine runs poorly or the ECU logs a fault regardless of any attempts to match the response, then the narrowband sensor will have to be reinstalled. The Wideband Sensor will then have to be installed in a separate position.

Using a wideband sensor in a permanent installation

As a test, we substituted a wideband sensor for the narrowband sensor in a 2004 Holden Astra. The S-curve output from the Wideband Controller was then fed to the car's ECU (in place of the output from the original sensor).

This worked OK and no error codes were produced by the ECU. However, we did have to keep the heater circuit to the original narrowband sensor connected to achieve this result.

In operation, the narrowband signal from the Wideband Controller cycles correctly above and below stoichiometric, but it appears to be twice as slow in its response as the original narrowband sensor. A new narrowband sensor also had a slower response than the original sensor.

The differences in the sensors are in the way the sensor is vented to the exhaust gas, the original narrowband sensor had side slits to allow fast gas entry. By contrast, the new narrowband sensor has its entry slits on the end while the wideband sensor uses small holes which are also at the end. As a result, the latter two sensors have a slower response because the gas is not replaced as quickly.

So, using a wideband sensor as a permanent installation may not be ideal in all cases, but will be OK for testing mixtures. Whether or not it is completely successful as a permanent installation will depend on the sensor orientation to the exhaust gas flow.

Other applications

As indicated earlier in this article, the Wideband Controller can be set up to monitor the oxygen content in air. It can measure oxygen concentrations ranging from beyond the standard 20.9% in normal air right down to 0%. That makes it ideal for checking the oxygen content of the air in enclosed spaces such as fire bunkers and walk-in cold storage containers, where the oxygen content can be depleted due to human respiration.

Another application includes areas where oxygen is depleted due to combustion. This includes areas heated with gas, oil, coal or wood fires. Other instruments should also be used to ensure clean air, including those for monitoring carbon monoxide (CO) and flammable gases.

In order to correctly read the oxygen content, the tip of the sensor must be exposed to the air being monitored, while the 'lead end' of the sensor must be exposed to normal air. In other words, the sensor has to be able to use normal air as a reference.

This means that the sensor must be mounted in the outer wall of the enclosed space, with its top section exposed to the outside air.

The voltage output from the Wideband Controller is directly proportional to the oxygen content in percent. So a 2.09V reading represents an oxygen content of 20.9%, which is the oxygen content of normal outside air. ***EPE***

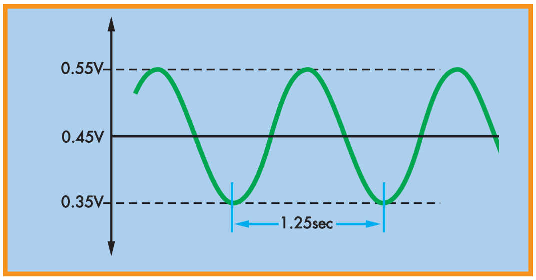


Fig.19: a typical narrowband sensor response with the engine warm and idling. The output oscillates above and below 450mV and can vary from just a few millivolts to about ±400mV (±100mV shown here).

TechnoTalk

Leaf Sweepings

Mark Nelson

Autumn: season of mists, mellow fruitfulness and sweeping up the fallen leaves. Actually it will be more likely be a season of freezing fogs by the time you read this, but never mind. Enjoy this autumn sweep-up of topical leaf-fall from Mark.

WHY do you read this magazine? For the electronics in it? Of course, but I bet the main reason is another word in the title – practical. So let's start with something practical.

Voltage drops

Voltage drop is a factor that electronicists ignore at their peril, and one of the first things we learn about diodes is that the voltage at the positive end is higher than at the other. Put another way, when current flows through a diode, a slight loss of voltage occurs, known as *forward* voltage drop.

This loss is fixed by the semiconductor material used to make the diode. Silicon diodes exhibit a forward voltage drop of about 0.65V, whereas the older germanium (alias geranium or flower power) have a forward voltage drop of about 0.1V.

In circuits with supply voltages of 5V, 12V or higher, this voltage drop is seldom a problem, but it's not easy to ignore when we're designing with low-voltage semiconductors. So how does an active diode with a forward drop of only 50mV sound? Pretty impressive, and the credit for its discovery goes to principal engineer Shawn Fahrenbruch of Microsemi Corporation in California.

The LX2400 product he designed, which is already in use by several industrial users, is a surface-mount chip measuring 7.5mm × 11.5mm × 2mm tall. The clever part is that the IC is powered by energy harvested from its own 50mV forward voltage drop.

Being a two-terminal device is what sets the LX2400 apart from most active device diodes, which require a power supply (unlike normal diodes, they are not passive devices). However, its price means that it's not the kind of component we'll be using in our next hobby projects. It has a very specific function, replacing bypass diodes in photovoltaic (solar panel) modules. These extremely high-reliability components have to last 30 years, carrying several amps at high temperatures. 'It is not something you are going to use in a DC-to-DC converter,' quipped Fahrenbruch.

Beat the thief

Equally practical, but in an entirely different way are the 'stealth' covers for iPads, TouchPads and other tablet PCs made by ReAuthored (**www.reauthored.com**). You could equally practically copy the idea and do it yourself, which is an even smarter idea. Puzzled? Read on!

It always beats me why people buy expensive cameras, PCs and other gadgets and then put them on display to the whole criminal world in a highly recognisable case that screams 'steal me'. The people at ReAuthored shared this point of view and make cases for your gadgets that are disguised as boring books. They explain that the original idea was an amusing whim, to give discarded books a new life by re-purposing them into Kindle cases, allowing the book to live on.

In just a few months, this idea expanded drastically. 'From iPad cases to Kindle cases to book safes. If it's rectangular in nature and we can find a book to fit it, we can and will make a case for it,' they explain.

There's no need for me to say much more; you can read the rest on their website. It's unfortunate that international postage charges will make these a rather expensive purchase, but I dare say other entrepreneurs will copy their idea.

Finally, I recommend you read their blog, with insights such as 'After contacting the local distributor for the type of glue we use on our cases, we were told that they could sell us bulk glue...for $2 more (per .71 oz) than what we buy it for at our local craft shop... huh?!? I thought bulk meant you pay less/item because you buy a lot of them at one time.'

Sense and sensitivity

When I was four years old I was given a wind-up clockwork train set that I enjoyed very much. After two years, I traded up to an electric one, which gave me a much enhanced 'user experience'.

Before both of these, I also had a Triang clockwork mouse, but I don't recall a similar kind of upgrade opportunity. But you can get electric eels (I don't think these make good playthings), which make active use of electricity. Actually, electric eels are not eels, but freshwater fish and they produce powerful electric shocks (up to 500V at 1A over a period of at least an hour without signs of tiring) for stunning prey and self-defence.

Now, scientists have discovered that another type of water creature, the Guiana Dolphin, has the ability to sense electric signals, which it uses to detect its next meal. The news appeared first in a learned journal of the Royal Society, but was soon taken up by media around the world.

Electroreception, reported the BBC, is well known in fish and amphibians, but this South American dolphin is the first 'true mammal' to sense prey by their electric fields. Primarily, it hunts and locates using sound, but at close range, it can also sense electrical signals of the kind produced in water when fish move their muscles.

Bats beware

Another interesting 'animal electrics' example appeared recently in Oxford's local paper, the *Oxford Mail*. It seems that bats are to be given their own railway signals to warn them of oncoming trains in a railway tunnel that has become a favourite roosting ground.

The trial, just north of the city at Wolvercote tunnel, has been commissioned by Chiltern Railways, which plans to offer a competing rail service from Oxford to London, and in the process increase the number of trains running through the tunnel. Bats communicate mainly by ultrasound, but Chiltern Railways probably don't speak bat language, so instead they hope triggering lights inside the tunnel when a train is on the way will alert the bats and encourage them to move temporarily.

Ecological consultant Geoff Billington, who is in charge of the trials, told the *Mail*: 'Bats generally avoid lit areas. The basic idea of the system is that the lights will come on and then a train appears. We hope that the bats may learn to associate the two things. It is clear they already scamper out of the way when we have observed them as trains pass through the tunnel now.'

The lights will be turned on and off 43 times each night, during a six-hour period when trains are not running. Ecologists will be stationed inside the tunnel and at its entrances to monitor the bats' behaviour as the lights go on and off.

Maybe *EPE* readers can come up with a cheap and simple electronic solution that announces in 'bat language' that they don't have to move, but may prefer to. Only one species of bat is involved, the Natterer, which should simplify matters.

Ginormous

7-Segment LED Panel Meter Display

Have you ever had the need for a digital display that can be read from across the room? How about across the factory? How about fifty or even a hundred metres away?

IF YOU THINK the picture above is big, it's about half the size of the real McCoy. That's all we could fit across the pages of *EPE*!

This LED display, which can be expanded to up to 10 digits, uses special LED 'light bars', each about 70mm × 15mm, and each of which contain two rows of six 200mCd to 300mCd LEDs in series. The ends of the light bars are angled so that when placed into the familiar 7-segment display pattern, they form ultra-large digits, each a whopping 150mm (six-inches) high.

And unlike some multi-LED displays we've seen, they don't cost upwards of a thousand dollars.

Each digit has its own pre-assembled PC board. As each segment can be driven independently, they can display the numerals 0 to 9 and many letters. There's also a matching (large!) decimal point alongside each digit, containg five LEDs in series.

Readability

Placed alongside each other, the display is striking – especially at night. Five digits (the number shown here) are some 600mm in width. When we checked how far away we could clearly read them, we gave up at 100m.

Like all LED displays, during the day visibility depends to a large degree on ambient light – for example, it's not as good in direct sunlight. Even so, it's pretty impressive.

OK, so that's the LEDs, but what do they display? For maximum flexibility, the display has been designed to accept multiple input signals. Parameters are set using a computer and saved to memory.

Input signal types are divided into three categories: analogue, digital and serial.

Analogue input modes include 0 to 5V DC and 0 to 20mA (or industrial standard 4mA to 20mA sensors can also be easily used). As well as voltage and current, these digits

FEATURES

- Large 150mm 7-segment display
- Easily add extra digits to display higher values
- 2 × opto-isolated inputs
- 1 × 10-bit 0-5V input
- 1 × 10-bit 0-20mA input
- RS485 serial, TTL serial
- RS232 serial or USB with optional converters
- 12V DC powered

OPERATING MODES
- 0 to 5V scaled
- 0 to 20mA, or 4mA to 20mA scaled
- Up/Down counter with reset and preset
- Quadrature up/down counter
- Tachometer RPM
- Frequency
- Up/Down second timers
- ASCII or Modbus serial over RS485 or TTL

Design by Greg Radion
(Ocean Controls Pty Ltd)
Article by Greg Radion and Ross Tester

can be configured and scaled to display virtually any analogue reading; for example, temperature, humidity or pressure.

Digital input modes include counter modes (quadrature, or up and down with reset and preset), tachometer (RPM), frequency and up/down timers.

Serial input modes include RS485, TTL and (with an optional converter) RS232 or USB, with the option of ASCII display or Modbus RTU controlled display. Various baud rates are supported. The device parameters are also set up using the RS485/RS232/USB connection to a computer with provided software or Modbus-enabled device.

Hardware

Various PC boards add together to achieve the above functions. We've already mentioned the giant LED display boards. A KTA-255 Large 7-Segment Controller PC board is mounted to the back of the first digit.

This board includes a microcontroller, constant current LED driver, shift register and all the circuitry needed to connect the various input signals. The microcontroller reads the input signals, and scales them according to the user settings, and then sends out the data to the shift register, which controls the data displayed on the 7-segment digit.

Of course, you're usually going to need more than one digit, and this is where the smaller KTA-256 Large 7-Segment Driver/Slave PC boards come in to play.

This has a constant-current LED driver, shift register and IDC header connections, for connection to the previous and next digits. One of these is mounted on the back of each additional digit.

Circuit details

Fig.1 shows the circuit diagram of the controller (KTA-255) module and Fig.2 the slave (KTA-256) module. As you can see, Fig.2 is basically a cut-down version of Fig.1.

There are some labelling shortcuts on the PC board – these are shown in green on the circuit diagram.

On the controller PC board, an AVR ATMega328 microcontroller (IC2) controls operations. Two of the analogue inputs have been connected to the VI and CI terminals, with 10kΩ inline resistors to provide some protection for the chip. The CI input also has a pair of resistors totalling 250Ω, which will generate a 5V reference for a 20mA signal passed through them.

Each of the seven segments is made up of a 70 × 15mm LED 'lightbar', as shown above. The PC board which carries them measures 112mm × 165mm.

A pair of opto-couplers isolate the digital input signals I1 and I2, and a DS3695 (MAX485 equivalent) converts RS485 levels to 5V TTL serial.

The output to the LED segments is delivered via a TLC5916 IC. This is a constant current LED driver/shift register from Texas Instruments. The operation of the TLC5916 is much like a 74HC595 shift register, in that it has a shift in data pin, a clock pin, a latch pin and a shift data out pin.

However, the outputs on the TLC5916 will regulate their current according to one programming resistor. The AVR controls the data stream to the TLC5916. The output of the TLC5916 is connected to the input pin of the next board using headers, conveniently labelled IN and OUT.

Configuration

The controller (KTA-255) configuration software sets up the display mode and parameters. User-configured parameters include:

- Operating mode
- Which digit to display the decimal point
- Scaling values
- Count-by values
- Reset values
- Display delay time (to reduce flicker)
- Debounce time (so that switch presses do not make multiple counts
- Modbus address
- Baud rate
- Parity

Not all parameters are relevant to each operating mode. The configuration software will hide the parameters which are not used.

To ensure that the configuration software can communicate with the controller, the communications parameters can be loaded to default at power up, by making a connection between MI and COM on K3 on the side of the PC board. This can be done with a bare wire, or by temporarily soldering a wire in place.

Let's take a look at the operating modes in more detail.

Analogue input: 0 to 5V

The Analogue 0 to 5V input mode will take a 0 to 5V signal, via the VI and COM terminals, and scale it according to the values used in set up. The allowable range is –32,768 to +32,767, and decimal places can be used as well.

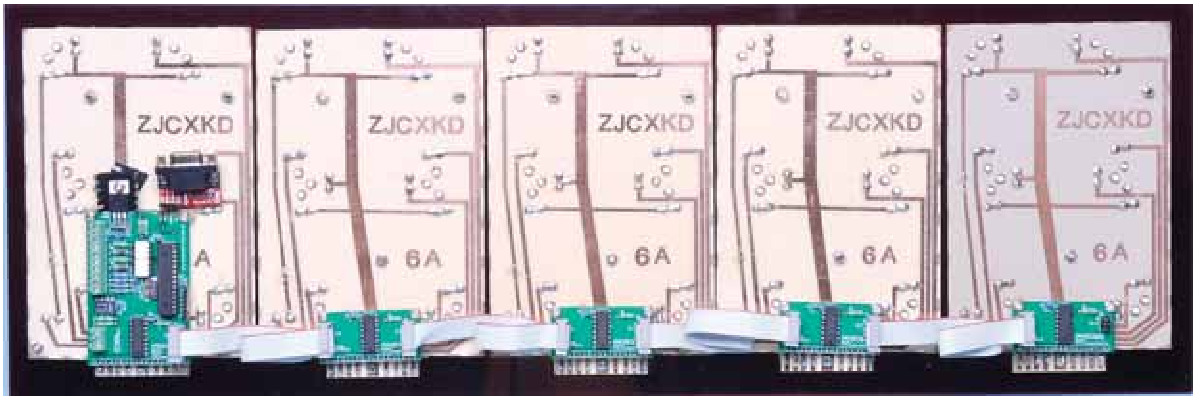
For example, to use as a 0 to 5V voltmeter, and assuming five digits to measure to four decimal places (0.0000 to 5.0000), the operating mode is set to 0 to 5V with the following parameters:

- Decimal place = 5 (show the decimal point on digit 5)
- 0V value = 0
- 5V value = 5

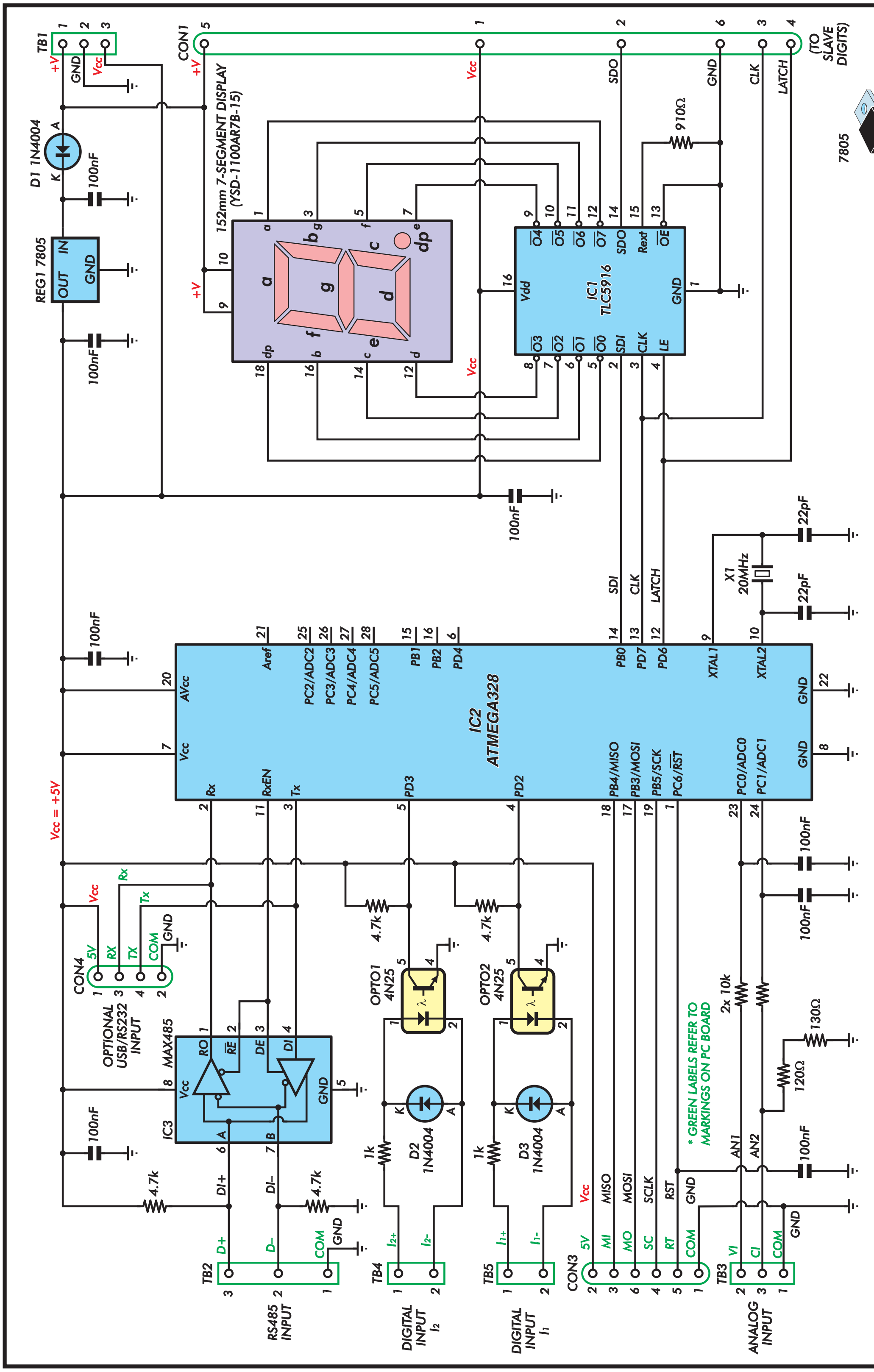
That is all that is required, but if the display flickers too much, the display delay time can be increased. If faster changes need to be seen on the display, then the delay time can be decreased.

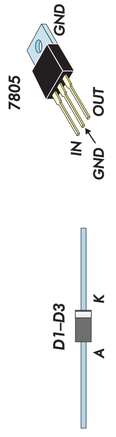
Analogue input: 0 to 20mA

The Analogue 0 to 20mA input is between terminals CI and COM, which includes a 250Ω load resistance.



The 'business side' of the large panel meter. The first display PC board (ZJCXKD) has attached the first-digit driver PC board (and in this case an RS232 interface). Subsequent displays have the slave driver PC boards, all of which are daisy-chained with IDC cable. The display PC boards are pre-assembled; other PC boards are available in kit or assembled forms.





GINORMOUS 7-SEGMENT LED PANEL METER

CONTROLLER/FIRST DIGIT MODULE

Fig.1: the first digit requires this controller circuit to drive it. This is shown opposite attached to the left-most display board.

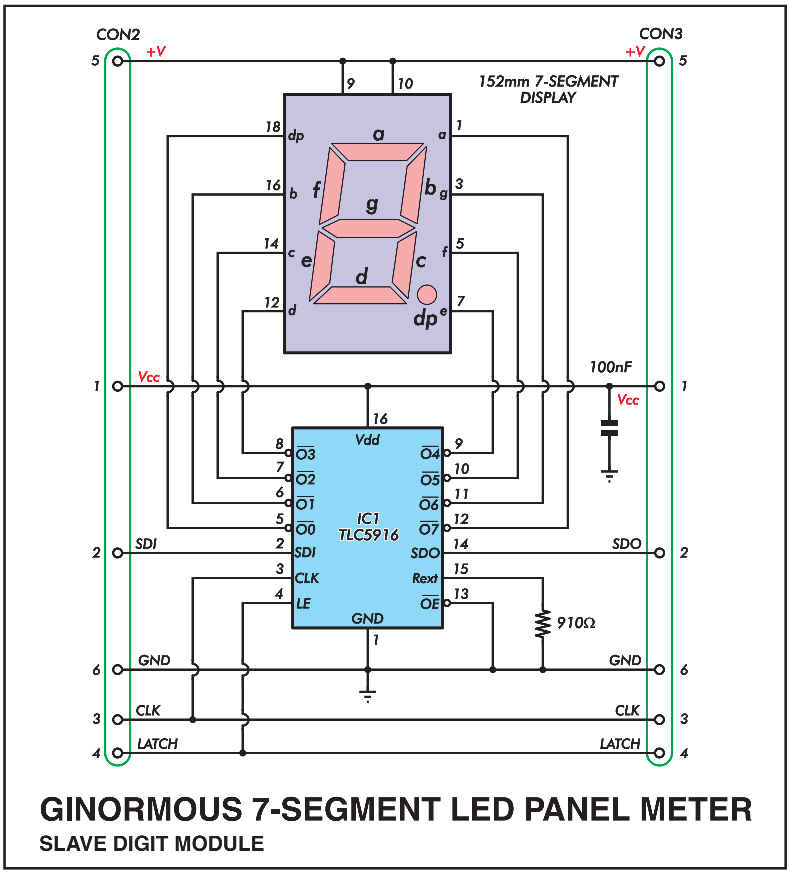


Fig.2: the circuit diagram of the slave digit controller – essentially a 'cut-down' version of the first digit controller Fig.1.

It can be easily used with 4mA to 20mA sensors, because the software allows either a 0mA or 4mA value to be entered and the other value is automatically calculated.

Most industrial sensors will use a 4mA to 20mA signal – a good example is a temperature sensor with 0 to 100°C output over 4mA to 20mA. Assuming five digits again, we can display to two decimal places, giving a range of 0.00 to 100.00.

The operating mode is set to 0-20mA with the 20mA value set to 100 and the 4mA value set to 0 (this will automatically set the 0mA value to –25).

The decimal point position can be set to 3 (or 4 for more accuracy, albeit at the cost of never actually being able to display 100.000).

Counter

In counter mode, an optically-isolated signal on inputs I1+ and I1– will add the 'count-by' value to the display each time it is triggered. To count down, a negative value can be used in the count-by value.

The count-by value can be from –32,768 to +32,767 (signed 16-bit), but the displayed values (count total) can be from –2,147,483,648 to +2,147,483,647 (signed 32-bit). Obviously, more than five-digits would be needed to display these values.

The I2+ and I2– terminals are used for another optically-isolated signal, this is used to reset the counter to the 'reset to' value

When a connection is made from VI to COM, the display will subtract the 'count by' value from the currently displayed value.

Up/Down counter mode

The Up/Down counter mode is very similar to the counter mode; however, in this mode, the optically-isolated signal on I2+ and I2– subtracts the 'count-by' value, and the non-isolated signal on VI and COM resets the display.

Quadrature

In Quadrature mode, a quadrature encoder can be used to count up and down. Phase A should be connected to I1+ and I1–, while Phase B should be connected to I2+ and I2–. The non-isolated input VI will reset the counter value.

It should be noted that each encoder edge is used for a count signal, giving four times the line resolution of the encoder; ie, a 1000-line encoder will give 4000 counts per revolution.

Tachometer

A tachometer pulse signal is fed into I1+ and I1–. If more than one pulse is given per revolution, then the number of pulses per revolution can be entered into the 'division' parameter.

Frequency

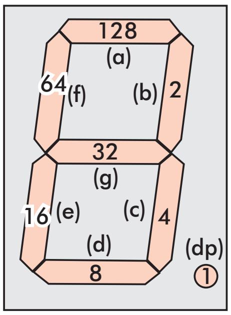
The Frequency mode is much the same as the Tachometer mode, except that the signal is not converted to RPM before being displayed. Maximum measured frequency is approximately 20kHz.

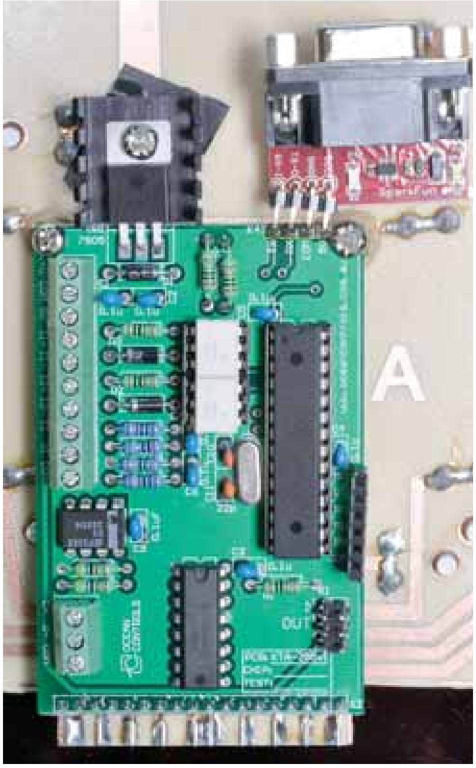
Up Timer

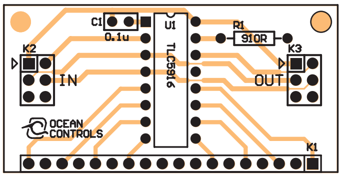
In Up Timer mode, the unit will display hours, minutes and seconds, with a decimal point to separate each.

The I1+ and I1– input starts the timer, the I2+ and I2– input resets the timer to zero, and the VI input pauses the timer.

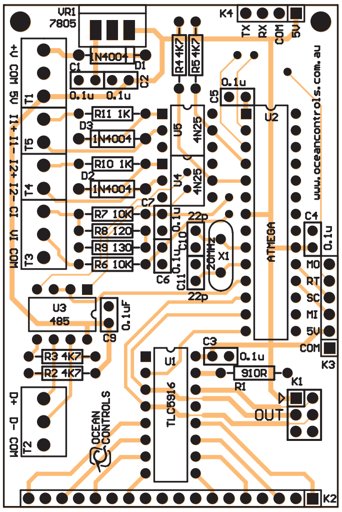
The timer will count upwards each second until the value set in the configuration is reached; if the set value is zero the counter will keep counting up.







Double-sided boards – only bottom layer shown



The K-255 and K-256 boards, shown here attached to the back of their display boards, with Fig.3 and Fig.4, the component overlays, between them. The (red) PC board at the top of the left-hand photo is an optional RS-232 serial interface.

Note how the 2nd, 4th, 6th, 8th, 11th, 13th, 15th and 17th header pins are cut off to prevent them shorting to the copper tracks underneath.

Down Timer

Similar to Up Timer mode, the Down Timer mode counts seconds; however, this time it is downwards. The reset value is set by the configuration software and the timer stops counting at zero.

ASCII

For easy connection to computer programs and microcontrollers, an ASCII mode has been added. Once the display has been put into ASCII mode and the baud rate and parity have been set in the configuration software, a link *must* be placed between VI and COM to make the device interpret the incoming data as ASCII, not set-up instructions.

There are always eight data bits and there is one stop bit. TTL serial data from microcontrollers and RS485 serial data can be sent directly to the controller. For RS232 or USB, an RS232-to-TTL converter or USB-TTL serial converter is needed. (Both of these are available from Ocean Controls – see later.)

To display numbers, send them to the display, followed by a Carriage Return character (a value of 13 or 0x0D). For example, '–1.234<CR>' sent to the display will show '–1.234' on the display.

The space character (32 or 0x20) will leave a blank space.

The DEL character (127 or 0x7F) will clear the display.

Letters can also be shown on the display, sending any of the characters

Holding register	Function
1	Value to display low 16-bits
2	Value to display high 16-bits
3	Decimal point position
4	Mode 0 = Modbus, 1 = 0-5V, 2 = 0-20mA, 3 = counter, 4 = U/D counter, 5 = quadrature, 6 =tacho, 7 = frequency, 8 = ASCII, 9 = up timer, 10 = down timer, 11 = Modbus
5	Low scale, count by value, pulses/rev (depending on mode)
6	High scale, reset value (depending on mode)
7	Display delay time
8	Debounce time
9	Modbus address 1 to 243
10	Baud 0 = 9600, 1 = 2400, 2 = 4800, 3 = 9600, 4 = 19200, 5 = 38400, 6 = 57600, 7 = 115200
11	Parity 0 = none, 1 = odd, 2 = even

Parts List – Ginormous 7-Segment LED Panel Meter

1st Digit Driver (KTA-255)

*1 PC board code 831 (labelled KTA-255v2), size 77mm × 52mm
1 28-pin IC socket
1 8-pin IC socket
2 6-pin IC sockets
1 TO-220 heatsink
3 3-way 3.5mm terminal blocks
2 2-way 3.5mm terminal blocks
1 2 × 5-way header pin set, 90°
1 18-way header pins, 90°
3 6mm M3 screws
1 M3 nut
2 5mm M3 nylon spacers
1 6-way (or 10-way) 15cm IDC connector cable

Semiconductors
1 TLC5916 IC (IC1)
*1 ATMega328 microcontroller, preprogammed (IC2)
1 DS3695/MAX485/LTC485 IC (IC3)
2 4N25/4N35 optocoupler (Opto1, Opto2)
1 7805 5V regulator (REG1)
3 1N4004 diodes (D1-D3)
1 20MHz crystal (X1)

Capacitors
8 100nF monolithic (C1 to C7, C9)
2 22pF ceramic (C10, C11)

*Available from the *EPE PCB Service*.

Also, see page 44 for details of kits and assembled units

Resistors

2 10kΩ	4 4.7kΩ	2 1kΩ
1 910Ω	1 130Ω	1 120Ω

Slave Digit Driver (KTA-256)

*1 PC board code 832 (labelled KTA-256v2), size 52mm × 25mm
2 2 × 5-way header pin sets, 90°
1 18-way header pins, 90°
2 6mm M3 screws
2 5mm M3 nylon spacers
1 6-way (or 10-way) 15cm IDC connector cable

Semiconductors
1 TLC5916 IC

Capacitors and resistors
1 100nF monolithic capacitor
1 910Ω resistor

Suggested display hardware

(n = number of digits)
1 Acrylic sheet, red, 6mm thick 200mm × (25 + 115n)mm
(Alternatively, for a higher contrast display 3mm red and 3mm grey can be sandwiched together.)
3n 12mm nylon spacers
3n 25mm M3 screws
3n M3 nuts

a-z (97-122 or 0x61-0x7A) will show that character.

As with all 7-segment displays, some characters will not show correctly and some can be mistaken (eg, 'D' and 'O'), but most are intelligible, especially in context.

If special characters need to be displayed, then the special character DC1 (17 or 0x11) is sent. The character following this is used to turn on each of the individual segments of the 7-segment display.

In the LED diagram (see page 40), each segment is labelled with a decimal value. To turn on a particular pattern of segments, add their values together and send that value after the special character.

For example, to turn on the top four segments and display a square, the value for each of those segments is added together: 128 + 2 + 32 + 64 = 226.

This is shown on the display by sending the value 17 followed by the value 226.

Modbus

The display controller can also be used as a Modbus slave. Modbus is an industrial protocol supported by many PLC's and SCADA packages. It consists of 16-bit holding registers and input registers, as well as 1-bit coils and status bits.

Only holding registers are implemented in the Display Controller (KTA-255). Further information on the Modbus protocol can be found at: www.modbus.org

If the controller has been put in Modbus mode, and the slave address, baud rate and parity are set via the configuration software, the controller will then be ready to use on an RS485 Modbus network or via direct connection on RS232, USB or TTL serial.

To display values, the first three holding registers are used. Holding registers 1 and 2 are combined together to give a 32-bit signed value from –2,147,483,648 to +2,147,483,647. Holding register 1 holds the lower 16-bits, holding register 2 holds the upper 16-bits. Holding register 3 sets the decimal point position.

To show '–98765.4321' on the display, holding register 1 would be set to 38735, holding register 2 would be set to 50465 – respectively the lower and upper 16-bits of the signed 32-bit number. These can be easily derived in the controlling application. Holding register 3 would be set to 5 to display the decimal point on the fifth digit.

Modbus Registers

As well as being able to display values directly from Modbus, the holding registers also hold all the settings for the controller; in fact, the configuration software uses the Modbus protocol to set up the controller.

In all except ASCII mode, the current displayed value can be read via the first three holding registers.

Assembly

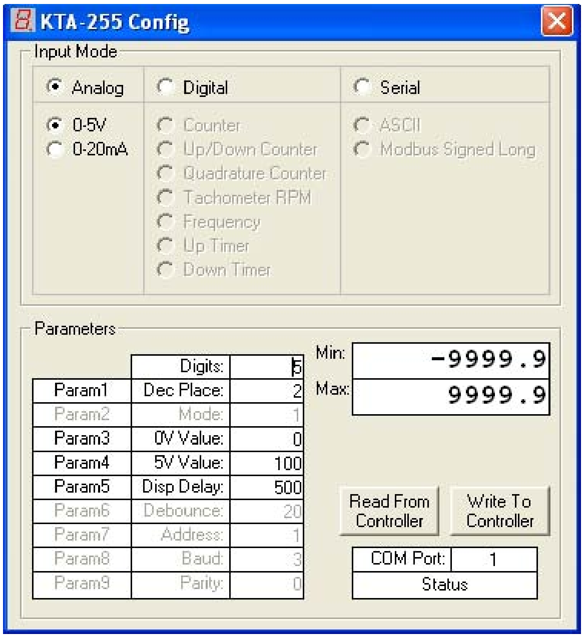
Both the Controller (KTA-255) and Slave (KTA-256) modules are available either as a kit of parts to assemble yourself or a fully built and tested module.

As previously mentioned, the individual 'digit' PC boards are only available pre-assembled.

If you choose the kits (which are cheaper), assembly of the PC boards is quite straightforward. Each board is double-sided, through-plated solder-masked and silk screened and has been through electrical testing. This means that it should be free from defects, but it is worth going over just to be sure.

The lowest components – resistors and diodes – should be placed first, and then the others mounted, generally in order of height.

Make sure you take a look at the diagrams and pictures to see where



The KTA-255 Configuration Windows software makes setting up the display very easy. The top radio buttons set the mode. At bottom, the relevant parameters are enabled and non-relevant parameters disabled. On the right, the maximum and minimum values and the decimal place position are shown for the number of digits you have. Once the parameters are to your liking, enter the COM port number the device is attached to and click 'Write To Controller'. Success or failure will be shown in the status box. Parameters from the display can be read out of the display device by clicking 'Read From Controller'

the components are placed. In particular, note how the connector K2 (KTA-255 or K1 on the KTA-256) is mounted underneath the board, making the connection to the back of the 7-segment display, as well as the 7805 voltage regulator with heatsink, bent 90° over the edge of the board.

Once the PC board is fully assembled, check your work for solder bridges or dry joints. If it looks OK, then you can proceed to the next step, mounting the PC board to the back of the display.

Attaching the PC boards

The assembled Controller (KTA-255) or Slave (KTA-256) PC boards are mounted on the back of the 7-segment 'digit' display PC boards, positioned so that some of the pins can be soldered to the tracks underneath.

While this may be enough to hold the smaller (256) boards in place, for added stability, the top ends of all the boards are screwed to very short (5mm) nylon spacers, glued to the back of the display board.

Eight of the pins on connector K2 (K1 on KTA-256) are not needed – in fact, they may short to tracks on the display PC board, so they *must* be cut off *before* mounting.

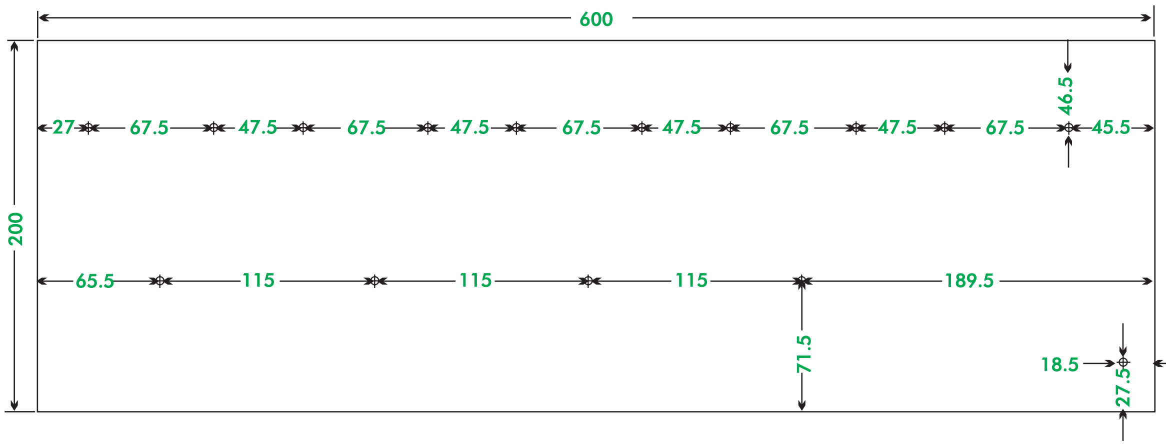
Make sure you do not cut off the wrong pins though. Take a look at the photo and you will see that the two centre pins are soldered in place, then every second pin is removed from the centre outwards, leaving 10 pins in total.

Apply a couple of blobs of glue to hold the nylon spacers in place.

A two-part epoxy glue is recommended. Hot melt glue is not recommended because the close-by 7805 regulator can produce quite a bit of heat, which could soften the glue.

If a metal bolt is used on the 7805 and heatsink, ensure it cannot short-circuit to the 7-segment display PC board – we used a small square of electrical tape where it touches the board.

The main controller board and driver boards can now be connected together using 6 or 10-pin IDC connector cables, taking note of the pin 1 index, denoted by the small arrow on the PC board.



Scaled drilling detail (don't use same size!) to suit a five-digit display. Either a 6mm red or a 3mm red plus 3mm grey sheet of acrylic work very nicely. You may prefer to mount differently to avoid screws coming through the acrylic panel.

Ginormous 7-Segment LED Panel Meter Display – Where to get it

The KTA-255 and KTA-256 have been designed by Ocean Controls Pty Ltd, who retain the copyright.

As previously mentioned, both kits and pre-assembled modules are available, which include PC boards, components and a programmed microcontroller (for 255s).

Each comes with the LED board, but not the mounting plastic (except for the 5-digit assembled kit which comes mounted on acrylic).

Approx GBP prices are as follows (all plus P&P):

Cat No	Description	Kit	Assembled
KIT-255	Controller Digit (without display)	£25.50	£31.50
KIT-256	Slave Digit (without display)	£10.50	£14.50
LCD-100	7-Segment Red 6.5in Display	£11.00	–

Nothing extra is required for use with RS485; however, for programming with either RS232 or USB serial ports you will need:

COV-201	RS232-TTL Serial Converter	–	£10.00
ARD-011	USB-TTL Serial Converter	–	£14.05

For more information

Ocean Controls
3/24 Wise Ave Seaford VIC 3198
Australia
Tel: +61 (0)3 9782 5882
www.oceancontrols.com.au

Testing

The easiest way to test the display is to connect a 10kΩ potentiometer to the 5V, V1 and common terminals of the main controller board (255), with the wiper to the V1 terminal. Apply power – the LED displays should come on with a random reading. Varying the pot over its travel should make the LED reading vary between 0 and 100.00.

Final mounting

How you mount the displays is really up to you and your particular application.

We have attached them to two sheets of 3mm acrylic, one tinted grey and the other tinted red, which gives a nice dark background but allows the digits to be clearly read.

Acrylic sheet is normally available, cut to your specified size, from plastics dealers.

Configuration software

The software to drive this project is available free of charge from the Ocean Controls website (see address above). This should give you virtually all the control you need to configure the giant display to read whatever you want.

An example of a configuration screen, setting up an analogue voltmeter, is shown on the previous page. Operation is quite self-explanatory. *EPE*

INTERFACE

By Robert Penfold

More on USB-to-serial interfacing

THE previous *Interface* article (Oct '11) covered the basics of using an FT245RL or a UM245R development module to provide a simple 8-bit input port for a PC using a virtual serial interface connected to a USB port. We will start this month's *Interface* by considering in more detail the use of a UM245R, instead of a 'raw' FT245RL chip. The FT245 is only available in surface mount versions that have minute pin spacing and are, therefore, quite difficult to use in a home-produced interface.

The standard 0.1-inch (2.54mm) pin spacing of the UM245R development module make it a more practical proposition that is worth the additional cost. When using this module you do not even need a custom printed circuit board, and I have used it successfully with stripboard and a breadboard.

Pin number

The UM245R is not just an FT245RL chip with an adapter to effectively convert it from a surface mount chip to a DIL type. For a start, the pin numbering of the basic chip and the module are different, which is inevitable with the module having 24 pins, while the FT245RL chip has 28. This seems to have caused some confusion with a few readers.

The pin numbering for the UM245R is shown in Fig.1. The FTDI development modules I have used seem to lack pin numbering on the device itself, but the function of each pin is clearly marked. This makes life much easier when prototyping one of these units with a breadboard.

The UM245R has a built-in USB connector, plus a couple of jumper blocks that can be used to select the required method of powering the module, and the operating levels of the data and control buses. These can work at 3.3V or 5V logic levels, or anything from 1.8V to 5V levels using an external reference source.

Fig.2 shows the equivalent UM245R interface circuit to the one based on an FT245RL in the previous *Interface* article (see Fig.4 in that article). The USB connector is shown as a separate entity, but it is actually part of the module. This connector provides the only way of accessing the two USB data lines, but in practice this should be all that is needed. The 8-bit data

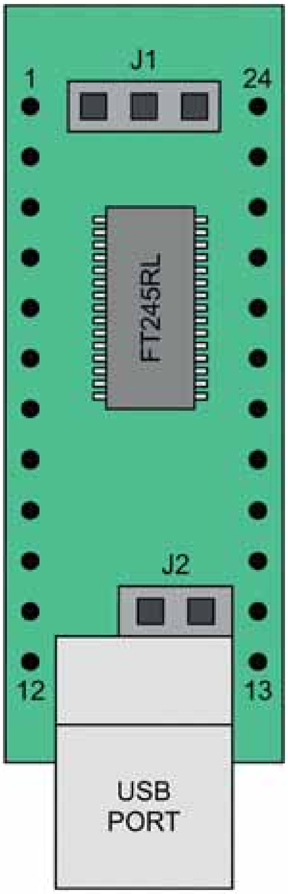


Fig.1. The method of pin numbering used for the UM245R module. Helpfully, the function of each pin is marked on the circuit board, but the pin numbers are not

bus and the four lines that are used to control the bus simply connect straight through to the relevant pins of the FT245RL chip, and they are used exactly as before.

Jump to it

There are two ground (Gnd) pins that connect to the 0V rail in the normal way, but care needs to be taken with the positive supply connections and the associated jumper block (J2) – see Fig.1. The jumper block enables the module to be powered from the USB port or from the interface's own power supply.

In FTDI's terminology, these are respectively known as the bus-powered and self-powered operating modes. The self-powered mode is only needed if the interface will require more than the fairly generous +5V at 0.5A that can be drawn from a USB 1.1 port, or +5V at 2.0A that can be drawn from a USB 2.0 port.

In Fig.2, the bus-powered mode is used, and this requires the 'jumper' on the J2 block to be present, which is the default setting. No harm will come to the module if the link is absent, but it will not receive any power and will obviously fail to work.

It is *essential* that this link is removed if the module is used in the self-powered mode, because leaving it in place would result in the USB supply and the interface's supply being connected together! It is reasonable to assume that this would have disastrous consequences for some of the components, and it will be dangerous.

USB terminal

The USB terminal of the UM245R at pin 14 is the +5V output of the USB port. In the bus-powered mode, this is connected via the J2 block to the Vcc supply pins. The USB pin can be connected externally to the Vcc pins, but doing so does not really serve any useful purpose, and it can simply be left unconnected.

In the self-powered mode, the interface's own +5V supply is connected to the Vcc pins, there is no link on the J2 block, and the USB pin can be used to provide an additional +5V supply. In practice, it is unlikely that this additional supply would be needed.

The most likely use for the USB supply output would be to drive an LED indicator light via a resistor of about 1kΩ in value. The LED would light up when the interface was connected to an active USB port.

VIO input

The VIO input at pin-4 of the module controls the logic levels used by the data and control buses of the circuit. These can be anything from 1.8V to 5V levels by supplying the appropriate voltage to the VIO input.

However, in most cases this input is left unconnected externally. Instead, it is connected internally to the +5V supply or to the internal 3.3V supply output of the FT245RL. The latter is available at pin 19 of the

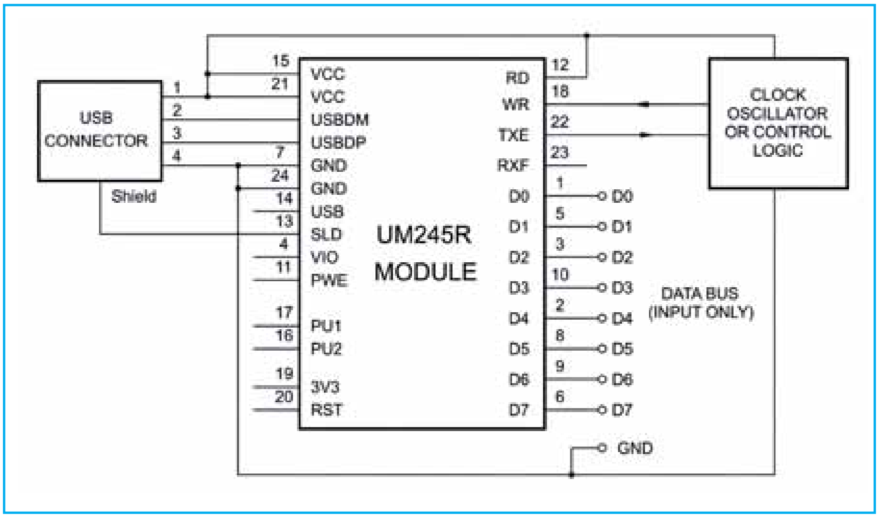


Fig.2. The arrangement used for a basic UM245R sending circuit. This is equivalent to the circuit of Fig.4 in the previous Interface *article (Oct'11)*

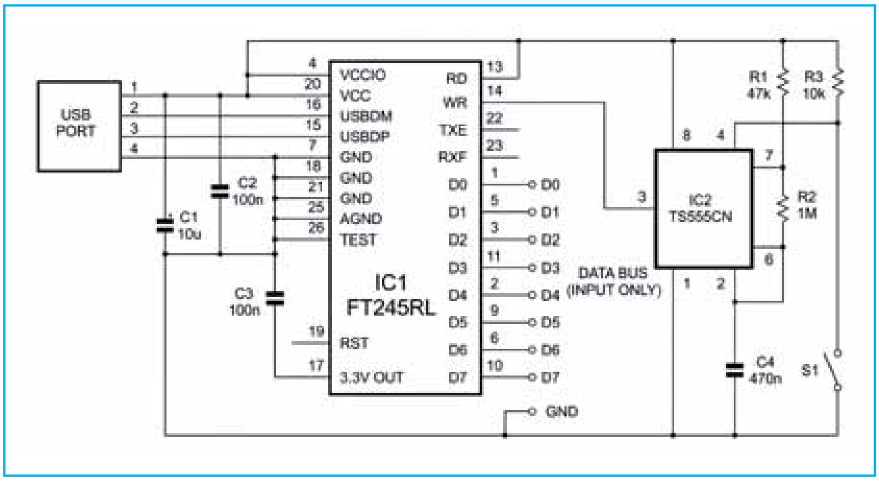


Fig.3. A simple interface based on the FT245RL that reads the inputs and sends data at a rate of about 1.5Hz. The operating frequency is easily changed by altering the value of C4.

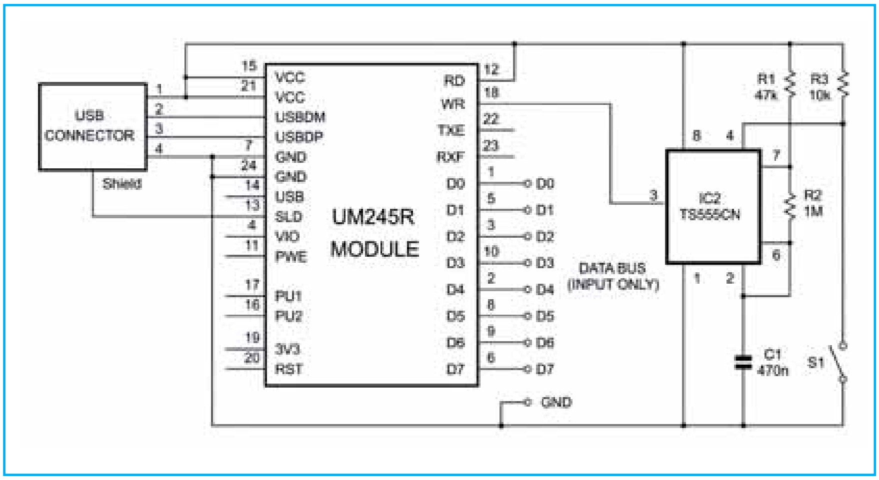


Fig.4. This is equivalent to the circuit of Fig.3, but it is based on a UM245R module rather than a 'raw' FT245RL chip

UM245R module, and it can supply up to 50mA to a 3.3V logic circuit.

The required logic voltage is selected via the J1 block (see Fig.1), and the default is for 5V operation, with pin 2 and pin 3 linked. Pin 1 and pin 2 are linked if operation at 3.3V logic levels is required. There must be NO link on the J1 block if a reference voltage is applied to the VIO input.

The RST pin connects to the reset input of the FT245RL chip, and it can be used to reset the chip. However, in most applications it is simply left unconnected. The PWE pin is an output that goes low when the USB port goes into suspend mode, but it is not required in most applications, and is left unconnected.

The PU1 and PU2 pins connect to a pull-up resistor, and they are not required when the module is used in the bus-powered mode. For self-powered operation, they must respectively be connected to the RST input and the USB output.

The supply decoupling capacitors in the original circuit are not required when using the UM245R module because they are included on the module. Of course, this is not to say that the interface circuit as a whole will not need any further supply decoupling. This obviously depends on the complexity of the complete circuit and the particular chips used, but the normal supply decoupling rules must be observed.

Ultra-simple port

Whether based on a raw FT245RL chip or a UM245R module, an 8-bit input port can be extremely simple indeed. The circuit of Fig.3 is for an 8-bit input port that uses an FT245RL chip. But the same simple control circuit works just as well with the UM245R module (Fig.4). Either way, it probably represents the easiest way of reading 8-bits of data using a modern PC. The following circuit description applies to the component annotation used in Fig.3.

The control circuit is just a simple oscillator based on a 555 timer chip (IC2), and this drives the WR (Write) input of the FT245RL. I originally used a slightly more complicated

circuit that provided a short pulse to the WR input in order to initiate a reading. However, the FT245RL only gives a minimum duration for this pulse, and seems to suggest that longer pulses will not cause a malfunction. This certainly seems to be the case, and the (more-or-less) square-wave signal used here does not seem to give any problems.

No handshaking with the FT245RL is used, and the TXE status output is just ignored. In order to work properly, the circuit must send data at a rate that is well within the capabilities of the baud rate used.

This is not a problem with the specified values for the three timing components (resistors R1 and R2, and capacitor C4), which give an operating frequency of only about 1.5Hz. I was just using the interface to periodically check a bank of switches, but some applications would obviously require a much higher operating frequency.

It is easy to change the operating frequency, which (in hertz) is approximately equal to 1.48/CR. Here C is the value of C4 in microfarads, and R is equal to the value of R1 added to twice the value of R2, and should be in megohms. The operating frequency is inversely proportional to the value of C4, and is easily changed by altering the value of this component.

For example, raising its value to 4.7µF would lower the operating frequency to around 0.15Hz, and reducing it to 47nF would increase the output frequency to about 15Hz. Incidentally, there are plenty of sites on the Internet that have useful 555 frequency calculators.

Using a baud rate of 19200, there should be no problem in having an operating frequency of up to a few hundred hertz. This is high enough for many applications, and is more than adequate to maintain an accurate onscreen reading.

Very infrequent readings could require impractically high values for the timing components. It has to be borne in mind here that high value capacitors tend to have relatively high leakage currents, and these can prevent very low frequency *R-C* oscillators from working properly.

Hard or soft

The hardware solution is to use a higher frequency oscillator and a divider chain to produce a suitably low output frequency. A software solution is probably the better choice, with a higher-than-required operating frequency being used and the software only using (say) every twentieth reading. In other words, use software to effectively provide the divider chain.

Switch S1, in conjunction with resistor R3, provides a means of stopping and starting the interface. As pointed out in the previous *Interface* article, it is not a good idea to have an add-on gadget sending data unless its accompanying program is running and reading the data. Resistor R3 normally pulls pin 4 of IC2 high, and the oscillator then operates normally. Operating S1 pulls pin 4 low and blocks the circuit.

Syncronisation

In some applications, it is important that the sending of data is properly synchronised to the arrival of fresh data. Otherwise, there is a risk of data being read while new data is being placed on the inputs. This would result in erroneous data being transmitted.

Problems of this type can arise when the interface is used with something like an analogue-to-digital converter. The solution is to integrate the interface with the control logic of the converter or other device, which is something that will be considered in the next *Interface* article.

Selecting power MOSFETs

EPE *Chat Zone* user ***tylex*** posted a query about selecting power MOSFETs, particularly the relevance of the $R_{ds(on)}$ parameter.

I am an old constructor, brought up on valves (shack warmers) and germanium (yes) transistors. I have never had to use the modern, new-fangled FET devices and have a couple of questions someone might answer for me please.

I am building a big (>30A) linear PSU, and would like to load test before use.

I have come across a couple of circuits from the 1990s using the BUZ10 and updated using BUZ384, both of which are now pretty much unobtainable. These are driven from the old faithful NE555 timer via a couple of pots from a 12V supply.

My question is: how close do I have to be to find an alternative which is much bigger and beefier current wise, for instance the STP60NF06L (Farnell). There are many others that appear to fit the bill, but I am unsure of the $R_{ds(on)}$ ratings.

Later, tylex added some more details:

... it was in my mind that there are any number of devices that appear to fit the bill that I require, namely:

Max input will NEVER exceed 30V DC. The current I need to 'sink' is >30A, my thoughts were;

V_{ds} 100V (well over rated), I_{ds} 60A+ which should run the device at about half its rated power and therefore run reasonably cool for test purposes, bearing in mind it will be being switched fairly fast,

It was just this R_{ds} business that I was unsure of, but I guess that in this application if the device chosen has been designed for fast switching, for instance, the STP60NF06L, IRF1503, STP40NF10L or STB60NF10 devices, then they ought to be a reasonable choice ?

As is often the case the basic issue was solved with the help of *Chat Zone's* contributors, with a number of suitable devices being discussed. The similarity between thermionic valves and MOSFETs was mentioned too. To add some more detail to this topic, this month we will look at $R_{ds(on)}$ of power MOSFETs, and some other characteristics, with reference to device structure and operation.

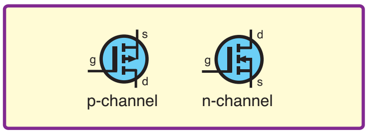


Fig.1. Power MOSFET symbols showing parasitic diode

Making a connection

Fig.1 shows power MOSFET symbols for *p*-channel and *n*-channel devices. A power MOSFET device has three connections – the gate (g), drain (d) and source (s). However, electrically, MOSFETs can be thought of as having four connections – the fourth being the substrate, or bulk silicon, in which the device is formed. In most discrete devices this is connected directly to the source, as indicated by the arrow in the middle of the symbol.

To understand power MOSFETs and their driver circuits, it's useful to first know a little bit about how MOSFETs are constructed and operate. The power MOSFET, like other MOSFETs, is basically a voltage-controlled device; that is, the gate-source voltage controls the drain-source current, with little or no continuous current flowing into the gate.

This is why MOSFETs are described as being similar to thermionic valves, where the grid voltage controls the current between anode and cathode. Bipolar transistors, on the other hand, require input (base) current to operate.

MOSFETs can operate as switches, controlled by the gate, and this is the most common application of high power devices. When the transistor is off, very little drain-source current flows and typically there is a large drain-source voltage, V_{ds}. The maximum V_{ds} rating of the device must be greater than this operating value.

When the MOSFET is switched on, there is typically a large drain-source current, I_{ds}. The I_{ds} rating for the device must not be exceeded here, but often $R_{ds(on)}$ is the more important device characteristic, as it determines the power dissipation ($I_{ds}{}^2 \times R_{ds(on)}$) at a given I_{ds}.

Linear operation

MOSFETs do not just operate as switches. With the device conducting, for relatively low values of V_{ds} and I_{ds}, they act as voltage-controlled resistors, with the drain-source resistance controlled by the gate-source voltage, V_{gs}. This is known as linear operation.

For a given V_{gs}, as V_{ds} is increased from zero, I_{ds} increases more or less linearly at first (the linear mode). However, at some point, further increases in V_{ds} do not result in increasing I_{ds}. This is called saturation – here I_{ds} behaves as a constant current controlled by V_{gs}.

In switch circuits (both power switches and logic gates) MOSFETs are switched between the off state and saturated conduction at a fixed V_{gs}. Linear amplifiers typically use MOSFETs in saturation, with varying V_{gs} used to control I_{ds}. There are also applications where linear mode is employed, so that a varying V_{gs} controls R_{ds}.

Fig.2 shows a simplified cross-section of a MOSFET, indicating the four connections: gate, source, drain and bulk. High-power MOSFETs have a different physical structure (which we will look at later), but their basic principle of operation is the same and can be described using Fig.2.

Conduction between source and drain in the device shown in Fig.2 takes place in a narrow channel region under the gate, and is controlled by the gate voltage. The gate is isolated from the rest of the device by a very thin insulating layer formed from silicon dioxide (known as the gate oxide). In the device shown in Fig.2, all the drain-source current flows through a horizontal plane. The term lateral

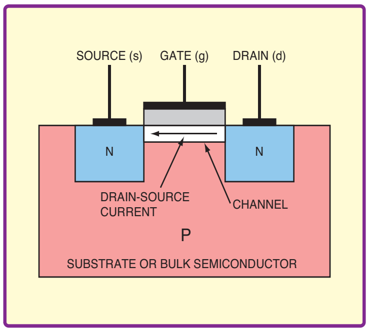


Fig.2. Lateral MOSFET used for low power applications

MOSFET is used to describe this type of structure, which is typical in the transistors used in digital ICs.

Basic operation

The basic operation of the *N*-channel MOSFET (as shown in Fig.2) is as follows. If we apply zero, low or negative gate-source voltage, the device is off because the *N-P-N* (source-bulk-drain) regions act as two back-to-back diodes. Only a very small leakage current can therefore flow from drain to source (or vice versa).

Here, *N* and *P* refer to the type of chemical used to 'dope' pure silicon to create interesting semiconductor behaviour. *N*-type silicon has more electrons free to take place in conduction than in pure silicon. *P*-type has fewer electrons, but these gaps can he regarded as mobile 'holes', which act like positively charged versions of the electrons in the *N* region. Thus, both *P* and *N*-type silicon conduct to some extent. Placing an *N* region next to a *P* region creates a *PN* junction, also known as a diode junction, through which current will usually flow in only one direction.

If we apply a positive gate-source voltage, the electrostatic attraction of this gate voltage will pull (negatively charged) electrons from the nearby silicon to the *P*-type region just under the gate. If sufficient electrons accumulate here, there will eventually be an excess of electrons, so the area just under the gate will *behave as if it is N-type silicon*.

At this point, we will have a created an *N*-type channel connecting the *N*-type drain and source regions. Thus we have an *N-N-N* path from source to drain, rather than the *N-P-N* back-to-back diodes previously described. Conduction can now take place from source to drain. The resistance of this conducting channel is an important part of a device's $R_{ds(on)}$ value, but source, drain, lead and other resistances play their part too.

Threshold voltage

The gate-source voltage at which the conducting channel just forms, and the device switches on, is called the threshold voltage. Power MOSFET threshold voltages are typically around 4V, but in order to fully turn on many of these devices for use at their full current rating, 10V or more may be needed. Thus, a driver circuit may be needed to translate the voltage levels in the control circuit (eg, 3V logic) to those required by the gate (eg, 10V).

Use of voltages well above threshold ensures saturated operation, in which the ON-resistance ($R_{ds(on)}$), voltage drop across the device, and power dissipation are minimised. We can consider the device to be either in the *off* state, where little or no power is dissipated, or the *on* state, where power dissipation depends on $R_{ds(on)}$ and the drain-source current. Low $R_{ds(on)}$ is, therefore, important in minimising total power dissipation. Low $R_{ds(on)}$ is a big selling point for switching power MOSFETs, lower dissipation at a given current means smaller device packages and less demanding thermal management, such as heatsinking in products.

Gate charge

Fig.2 shows that the gate, gate-oxide and channel form a conductor-insulator-conductor structure, in other words, a capacitor. In order for power MOSFETs to switch quickly and efficiently, sufficient current must be available to quickly charge or discharge the gate capacitance of the device.

Saying that a MOSFET is voltage controlled and has very high input impedance may give the impression that switching it is effortless. This is not the case – charge must be moved to switch a MOSFET, which takes time and energy; however, a MOSFET does not require the continuous input current needed by a bipolar transistor to hold it on.

The effort required to switch a MOSFET is indicated by the amount of charge which has to flow during the switching operation. Gate charge values, Q_g, are often specified on power MOSFET datasheets. Like $R_{ds(on)}$, the smaller the value of Q_g the better – the value of $R_{ds(on)} \times Q_c$ is sometimes used as 'figure of merit' to indicate how good a power MOSFET is. In crude terms, making a MOSFET larger reduces $R_{ds(on)}$ but increases Q_c, so getting a better figure of merit is not easy. Larger devices are also more expensive.

The driver circuit's source resistance and the resistance of the wiring, both inside and outside the device, will cause the gate voltage to follow an *RC* charging curve, so a switching MOSFET will spend some time in-between being fully on and fully off. During this time the device may dissipate a lot of power, a problem referred to as 'switching losses'. Therefore, the drive circuit must be able to supply enough transient current to charge the gate capacitance at the required rate. In some cases, this current may be quite substantial, particularly for large very high power devices, or where paralleled MOSFETs are being used. Lower gate capacitance, and hence Q_g, means that the MOSFET can be switched at higher frequencies.

The effective capacitance of the MOSFET gate, and hence the drive current required, is increased by the Miller effect. The Miller effect occurs when a capacitor is connected to produce negative feedback in an amplifier – the gate-drain capacitance in this case. The capacitance is multiplied by a factor related to the amplifier gain to get effective capacitance.

The dynamic capacitance of a power MOSFET gate during switching is complex and can be difficult to analyse. Basically, all this means is that driving the gate is probably harder than it first looks, hence the need for good driver circuits.

Vertical conduction

The physical structure of the MOSFET device shown in Fig.2 is not easy to use when making high power devices – it is difficult to make the cross sectional area of the conducting region big enough. If this area is too small, the transistor's $R_{ds(on)}$ will be too high, resulting in excessive power dissipation when it is conducting large currents. The basic solution is to use vertical rather than horizontal current flow.

Vertically conducting power MOSFETs can have either flat (planar) gates, as shown in Fig.3, or use groove or trench structures, as shown in Fig.4. Terms such as 'trench' and 'deep gate' occur in MOSFET product names to reflect the shape of these structures. In general, trench structures achieve lower $R_{ds(on)}$. The actual structures of real power MOSFETs are more complex than those shown in the diagrams here (for example the *N*-type area connected to the drain has different regions with different doping levels).

Discrete MOSFETs can be connected in parallel to provide higher current handling capability (effectively reducing $R_{ds(on)}$). Unlike bipolar

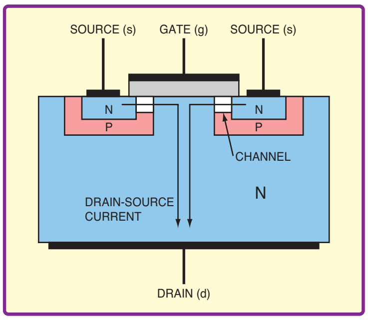


Fig.3. Simplified planar-style power MOSFET structure, showing vertical current flow.

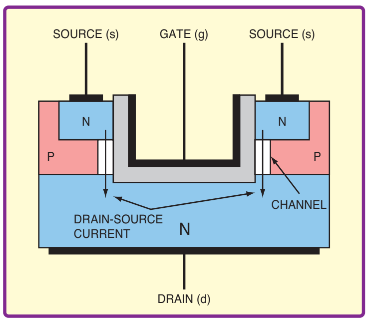


Fig.4. Simplified trench-style power MOSFET structure, showing vertical current flow.

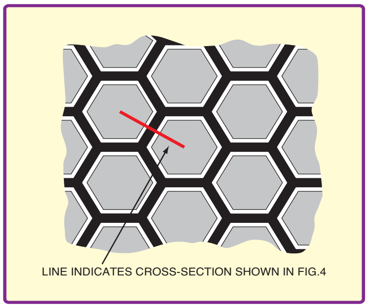


Fig.5. Top view of a MOSFET using hexagonal repeated cells to form parallel transistors. The grey areas form the source and black areas are the gates.

transistors, parallel MOSFETs do not always suffer from destructive current hogging and thermal runaway. As well as being useful in circuit design, paralleling MOSFETs is exploited by device manufactures to enhance device performance.

Many transistors are created in parallel in silicon to give high current capability. A variety of shapes can be used for these repeated structures, including strips, squares, triangles, or, as illustrated in Fig.5, hexagons (HEXFET is a name used by International Rectifier,). Some power devices have many thousands of parallel transistor cells.

The structure of modern power MOSFETs is highly optimised to provide good performance, but possibly only in one mode of operation. For example, a device optimised for switching may quickly fail if used in linear mode under apparently less power demand that it can handle when switching.

Typically, planar devices are better for linear operation, and trench devices provide the best switching performance. Manufacturer's selection charts and datasheets should provide information on intended applications and should be taken into account, as well as raw data such as $R_{ds(on)}$.

Max's Cool Beans

By Max The Magnificent

I can't help myself. I keep on finding all sorts of cool apps for my new iPad 2, and I cannot stop sharing them with anyone who doesn't get out of my way fast enough when they see me coming.

Can you hear me?

But before we talk about apps, let's first consider noise-cancelling, headphones. If you are in a noisy environment like an airplane, there's going to be a lot of ambient background noise from the engines, air system, and so forth. Even if you have really great headphones that have lots of padding, some amount of this noise is going to get through and interfere with the audio signal you are trying to enjoy.

The idea behind noise-cancelling headphones is that, unlike regular headphones, they have a microphone on the outside of each earpiece. These microphones pick up the ambient sound, which is amplified, and fed into your earpieces; the trick being that it is fed back 180 degrees out-of-phase with the original noise, which means the two cancel each other out (like ripples in a water tank) leaving only the audio signal you wanted to listen to.

I purchased some Bose noise-cancelling headphones several years ago, and these are pretty good, but not as effective as I was hoping (I'm sure they have better ones now). Unfortunately, I forgot to take these headphones with me on a recent trip to give a talk to a bunch of hardware engineers at Microsoft in Seattle. This was a pain because I had downloaded a couple of movies to my iPad that I intended to watch on the flight.

Anyway, I decided that I deserved a treat, so I visited the electronics store in the airport and invested in a pair of Sony MDR-NC500D noise-cancelling headphones. I'm embarrassed to say how much these little beauties cost, but I'm happy to say that they were 100% worth it. The quality of the sound is simply incredible. In one of the films there was a quiet part where we were in the forest and all you could hear were crickets and bird calls … and I COULD hear them perfectly! In fact, I kept on turning the headphones off just to remind myself of how noisy the plane really was.

Notes Plus

The iPad comes equipped with its own Notes app, but even if I were being kind, I'd have to say that this is rudimentary at best. So I started to look around and I discovered an app called Notes Plus. This little scamp is in a league of its own – this is the sort of app that fully utilises all of the iPad's capabilities and turns the iPad into a full-up professional tool rather than a toy. The price of Notes Plus from the app store ranges between $0.99 (£0.63GBP) and $4.99 (£3.15GBP) depending on whether there's a special offer or not, but whatever the price it's worth every penny.

So why is the Notes Plus app so amazing? Well, first of all it's incredibly intuitive and easy to use. It's also got a wealth of well thought out productivity features that happen behind the scenes to make your life easier.

The basic idea is that you store your notes in a Notebook. When you create and name a new notebook it starts with a single page, but you can add pages as required. You can also copy pages, rearrange the order of pages within the notebook, delete pages, and so forth. You can also create folders (and folders in folders) and then create your notebooks in these folders, all of which helps you organise things.

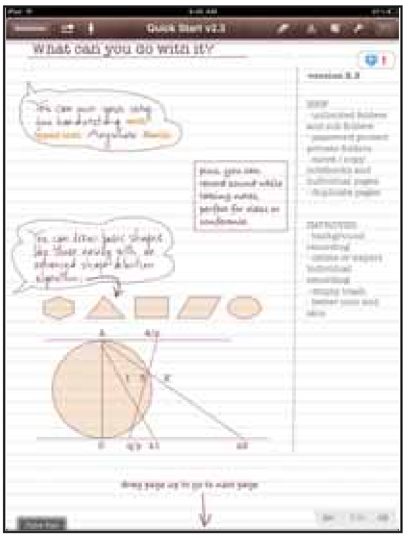
You can enter handwritten notes with your finger or with a stylus. I purchased a stylus, but to be honest I find it easier to use my finger. You can create one big handwritten note or lots of smaller ones wherever you want them to appear on the page.

Rather than enter handwritten text, you can use the pop-up keyboard (or a physical keyboard if you have one). Again, you can create one large note or lots of smaller notes, and you can mix things up and have multiple handwritten and typewritten notes all over the page.

In good shape

You can also draw shapes, which is really, really cool. If you draw a line (or a series of connected lines), or a triangle, or a square/rectangle or a circle, Notes Plus automatically detects this and converts it into a sharp vector-based object. You can specify all sorts of things like outline colour, fill colour (if any), transparency, and so forth – otherwise the system will simply use your previous settings.

Once you've created one of these vector objects, you can select them, resize them, move their vertices, or move the entire object around the page. Furthermore, once you've created any object, like text (handwritten or typed) and shapes, you can change its attributes (size, font, line-width, colour.) and you can move it around the page. You can also place objects on top of other objects, like text on top of shapes.



Things just keep on getting better and better, because you can use the iPad's built-in microphone to record audio notes that will be associated with whatever page you are on in your notepad. Later, if you wish, you can export your entire notebook (or one or more of its pages) to iTunes as a PDF, or to your photo albums as an image. You can also email your notebook (or individual pages) as a PDF or as an image.

The bottom line is that Notes Plus has my official seal of approval and it wins one of my coveted 'Ten Cool Beans' awards. Until next time, have a good one!

Win a Microchip 8-Bit Wireless Development Kit

EVERYDAY PRACTICAL ELECTRONICS is offerng you the chance to win a Microchip 8-Bit Wireless Development Kit. The Kit provides eXtreme Low Power PIC microcontroller users with an easy-to-use platform for developing, evaluating and testing low-power, cost-effective embedded wireless connectivity. It features a pair of wireless PICtail daughter boards, two battery-friendly 8-bit XLP PIC MCU development boards and the ability to add additional nodes to create a larger wireless network.

This kit includes Microchip's MRF24J40 transceiver module and also features Microchip's PIC18 XLP microcontroller family. The 2.4GHz MRF24J40 is an easy-to-use evaluation and development platform for IEEE 802.15.4 application designers. The kit includes the complete hardware needed to rapidly prototype wireless applications. The demonstration kit is pre-programmed with MiWi protocol stack and you can find the demo instructions in the user's guide.

Microchip's MiWi development environment (DE) provides a complete ecosystem for designing star and mesh wireless networking products. The MiWi DE comprises Microchip's free, proprietary MiWi P2P, MiWi and MiWi PRO star and mesh networking protocol stacks; as well as the multi-purpose Wireless Development Studio (WDS), with cross-platform support for Linux, Mac OS and Windows operating systems. The MiWi DE simplifies the development of ISM-band wireless networking applications for the home and industrial automation, wireless sensor monitoring and control, and smart energy markets.

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CLOSING DATE

The closing date for this offer is 31 January 2012

PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

The dsPIC processor family

THIS month, we take a look at a new processor family, the dsPIC33. Although new to *PIC n'Mix,* the devices have been available since 2004; we've overlooked them until recently as they occupy a rather specialised area – digital signal processing, or DSP.

This is a branch of engineering that deals with processing signals, such as filtering or separating out the underlying frequency spectrum using digital rather than analogue techniques. DSP techniques are found in areas such as radio astronomy, radar and medical imaging and while interesting the applications to hobby electronics are limited, and so we've passed the devices over – until now.

So what makes the dsPIC from Microchip a digital signal processor? It's down to a combination of the peripherals, specialised CPU instructions and speed of the device. The dsPIC family of parts provide peripherals to connect to external CODECs and have fast on-chip ADC and DACs not found on other processors.

They are also fast 16-bit devices, capable of running at 40 million instructions per second. There are some new, interesting instructions too, which are present specifically to support common digital signal processing algorithms such as 'multiply and accumulate'.

A number of engineers have expressed doubt over the utility of the dsPIC due to its relatively low performance, as modern DSP processors operate in the GHz range. The dsPIC is, however, a low-end device with a price to match, so there should be plenty of uses for it at the bottom end of the processing market.

From our point of view, however, it's the new hardware peripheral features that are of most interest.

High quality audio

Generating audio (speech in particular) has been something that's interested us here in the *PIC n' Mix* labs since the 1970s. Various techniques have been used over the years, from pulse width modulation on a single output pin of an EPROM to an 8-bit resistor DAC, as used on the *Halloween Howler* project in *EPE* a few years ago.

All of these designs produced recognisable sound output, but with a low data rate and resolution the quality was poor at best. The main limitation of these systems was the resolution of the sound samples. With eight data bits you have only 256 unique voltage levels, which reduces the precision with which you can represent your sound.

Another limitation of the circuits was the way in which the audio signals were processed. Outputting a new sound sample at a data rate of 22kHz for example (about the maximum rate for a simple microcontroller) resulted in processor noise appearing in the audio signal range we were trying to listen to. This meant that accurate low-pass filters with sharp cut-off performance were required to remove these signals, complicating the circuit design. A much better approach would have been an on-chip peripheral with the following features:

- 16-bit resolution
- 44.1kHz sample rate (CD quality)
- Two channels (for stereo)

Family matters

You can imagine our delight when we discovered the dsPIC33FJ family of processors provides just this. The chips are inexpensive and readily available from the usual suppliers in 28-pin DIL packages, ideal for hobbyists.

On closer examination, there are further interesting features associated with this peripheral.

Differential outputs: Each DAC (digital-to-analogue converter) provides differential output signals. When these are used to feed an amplifier with differential inputs (such as an op amp), the effect of noise from the processor circuit is significantly reduced.

256 times oversampling: The DAC will split each input sample into 256 slices, and perform the digital-to-analogue conversion on each of these new samples. While this does not increase the true sample rate, it does result in the sample clock 'noise' being much higher in frequency – well outside the audio range – and therefore much simpler to filter out.

DMA transfers: Now let's admit it – nobody likes using DMA transfers. They are complicated and have odd, poorly defined quirks. If we are going to be transferring audio samples at a rate of 172K bytes per second, however, we are going to need all the help we can get. And as it turns out, the DMA feature is essential.

Time to play

We've had two projects in mind for a few years now, awaiting a processor with decent sound support. A 'theatre sound effects unit' and a fully stand-alone 'drum synthesiser'. While both of these can be adequately implemented using a laptop PC, a small, cheap, dedicated device has its benefits. Not to mention the fact that we will have the fun of building it ourselves.

The first step is to test out the capabilities of the interface and determine exactly what level of quality can be realised. Out with the breadboard!

There are a number of datasheets that are needed to understand how to use the dsPIC to produce audio. The first is the part-specific datasheet, DS70292D. This contains pinouts, electrical characteristics and short summaries of the various peripherals.

If, like us, you are coming to this part for the first time, you need to look at the more detailed family reference manual. This is a large manual split into individual documents, one per peripheral. We are going to be interested in the *Audio Digital-to-Analogue Converter* DS70211B, and the *Direct Memory Access* document, DS70182A.

You are free to download all the manual if you wish, but at fifty-five different documents, that's a big read. The trick is to try and use as few references as possible, as otherwise you will flounder in a sea of complex cross-references.

When you find that you do not understand a section in a datasheet, download just the co-responding section from the manual. If that fails, look for examples on the web. If that fails, ask on the *EPE Chat Zone* forum!

Circuit design

Fortunately for us, within the DAC manual there is an application example circuit for hooking up the DAC outputs to some op amps (section 33.8 for those who are interested.) This provided the basis of our audio design – although we simplified it a little (removed the headphone amp becauses we are feeding an external amplifier; using the MCP6024 op amp

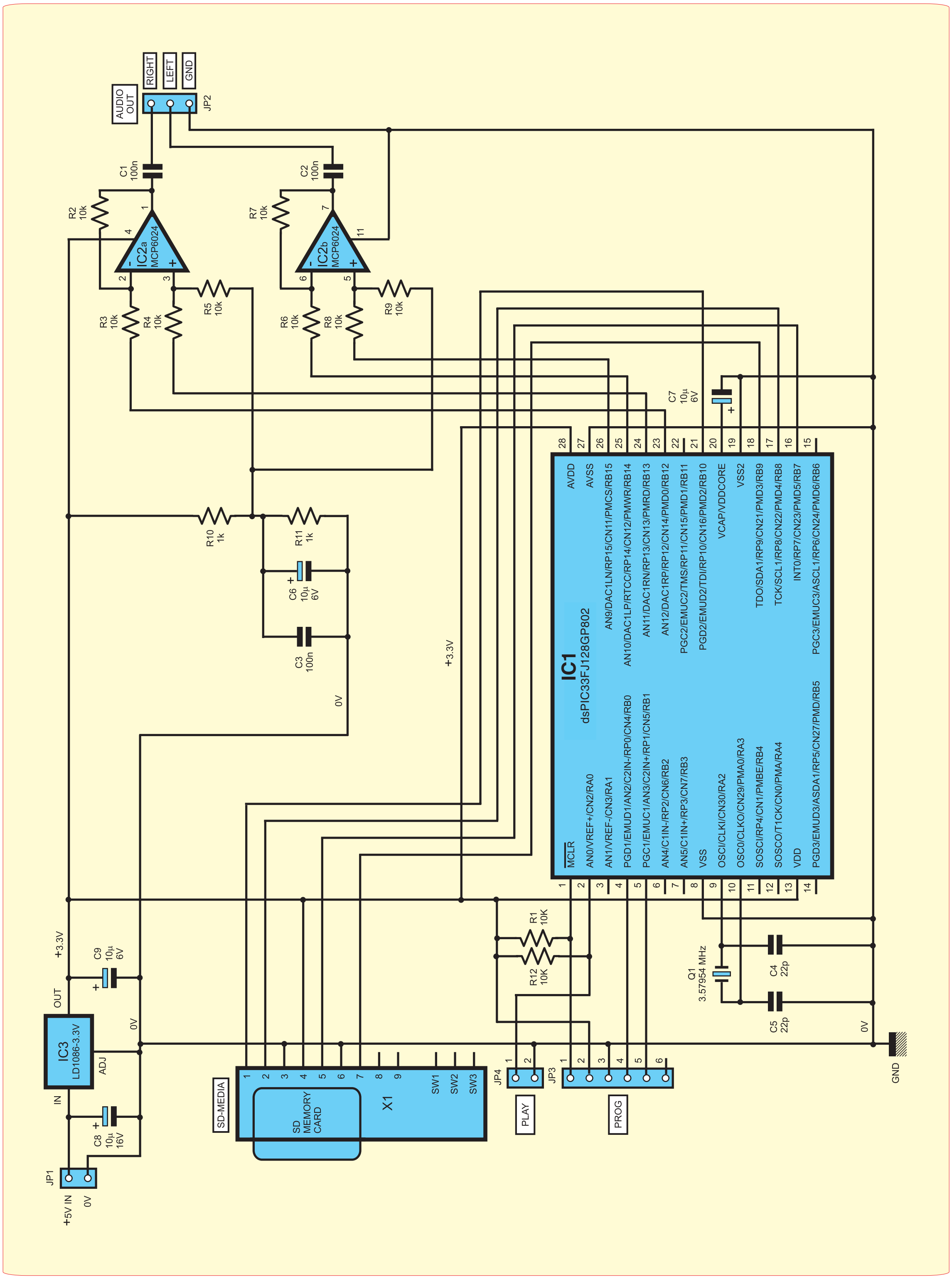

Fig.1. Mike's audio circuit diagram using Microchip's dsPIC33FJ128GP802 processor

rather than MCP6022, as the MCP6024 was readily available.) The main datasheet also provided an example of a minimal circuit for the CPU (see section 2.1), so we were well on our way to a usable hardware design.

Besides the addition of a switch to provide some interaction with the software, the next question was 'where will the sound samples come from?' We know they will be large, as we are hoping for a transfer rate of 172KB per second. There isn't much point designing something that can generate high quality audio, if you are only going to store a few seconds worth of sounds!

Memory cards

The obvious choice is removable flash memory. We settled on SDMedia cards as these are cheap, have a simple electrical interface and are physically robust enough to be able to cope with frequent removal and re-insertion. Although USB memory sticks might

appear better, the physical interface is more complicated and you would end up with a design where the memory stick is 'hanging out' of your case somewhere.

With SDMedia cards, the socket can be recessed within a case, making it appear to be an integral part of the design. And as our final project will be used in schools, we wanted something that would be tough enough to withstand 'over enthusiastic' use.

We've covered memory cards before in *Pic n' Mix*, so their use was no mystery – plus, Microchip have a library for interfacing memory cards to the PIC, so we knew the software interface would be easy.

The final hardware decision was what kind of power source to use. The dsPIC runs at 3.3V, which is fine for interfacing to SDMedia cards. At some later point we would want to improve the design with a standard two-line LCD module, which run at 5V. So, for this reason, we settled on using a regulated 5V power 'brick' as the source of power and our (now favourite) LD1086-3.3V linear regulator.

Circuit details

So, by cobbling together a combination of previous and example designs, the circuit diagram in Fig.1 was produced. JP2 provides the audio output connection to an amplifier, JP4 is for a push-to-make momentary switch (for whatever user interaction we decide on) and JP3 is the normal PicKit programming interface.

The choice of crystal may seem odd, at 3.579545MHz, but this was arrived at to allow a combination of accurate 44.1kHz sample rate and as close to 80MHz operation as possible.

There is still a question remaining: how will sound files be stored on the memory card?

As we will be using a PC to download our sound samples to the card, it makes sense to use the Microsoft FAT filesystem. While this could be complicated to implement from scratch, Microchip already has a number of library functions within their application library that make this a breeze. And it completely removes the need for any special software at the PC end; you just insert the memory card into your PC (or into a memory card USB interface, if your PC does not have a memory card slot) and then you copy the files onto it, as though it were another drive.

There is another issue we have to deal with though; our simple design will insist that your sound samples are 44.1kHz, 16-bit stereo (ie, CD format audio.) Not all sound samples are; if you want to use such samples, you will have to convert them. Some very good, free programs are available on the Internet to do this. We recommend Audacity as it is free, open source and easy to use.

But let's get back to the circuit. The SDMedia card interface is extremely simple. The cards support a number of different interfaces, and we are going for the simplest – SPI, which uses just four of the nine card edge connections. While most SDMedia connectors provide extra connections for presence and write-protect detection we will ignore these, as they can be handled in software (and as a media player, we will have no need to write to the card anyway.)

Using the 28-pin DIL dsPIC, there are enough spare I/O pins to allow for more buttons and even an LCD interface, so there is plenty of growth potential in this simple circuit. There really isn't much else to say about the design; it's sufficient to evaluate the performance of the DAC peripheral, and to establish whether or not we can suck data off the SDMedia card quick enough to be able to play continuous stereo audio sound. And to evaluate that, we need some software.

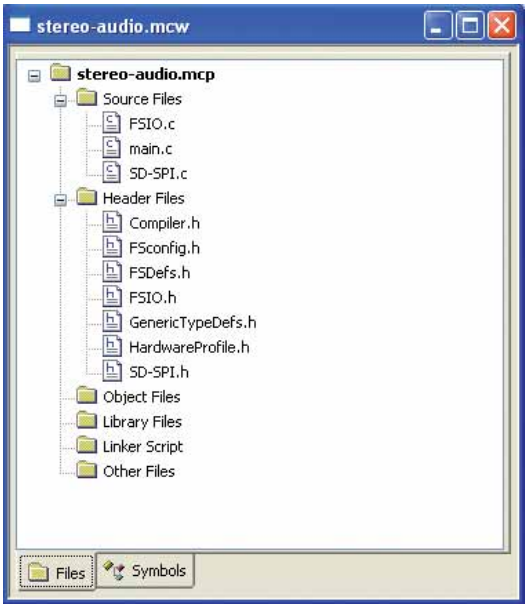

Fig.2. Source code layout

The code

The complete example project source code can be found on the *EPE* website. This can be opened in MPLAB, built, and the resulting .hex image downloaded into a processor without modification (assuming that you have followed the circuit design in the article.)

You will need to install the C30 compiler (if you do not already have it installed) which is freely available from the Microchip website. Although only the 'lite' version is available for free, this is a fully functional C compiler and is perfectly adequate for hobbyist use, and can generate unlimited sized projects.

We also downloaded the Microchip Application libraries, which contain the Memory Disk Drive File System software, to provide the access to the SDMedia card. You don't have to, because we have extracted the files required and placed them in our example project (which is permitted by the licence of the Application Library.)

The first issue, however, is building a project that actually powers up the processor to prove we have wired the circuit up correctly. This is often the trickiest part, especially for those of us without oscilloscopes.

The project is implemented in the C programming language, as this matches the language used for the application library (and is, really, the most appropriate language for a processor of this complexity.)

The first steps are to configure the phase-locked loop within the processor to enable the crystal oscillator multiplier, bringing our oscillator speed up to 78MHz. Next, we perform the more usual operations of configuring I/O pins for input, output or special functions (such as mapping pins to the SPI bus.)

We also need to configure the Microchip Application Library source code to match our particular circuit. Fortunately, Microchip have made this simple by bringing all the circuit-specific dependencies into a single file – **hardwareprofile.h**. All we need to do here is identify to which pins the SDMedia card is connected.

From this point on, reading files from the SDMedia card is as simple as issuing the following commands:

```
FSInit();
pointer = FSfopen ("SOUND.WAV", "r");
FSfread (receiveBuffer, 512, 1, pointer);
```

This will read 512 bytes from a file on an SDMedia card.

The digital-to-analogue converter peripheral takes a pair of 16-bit numbers and converts them into an analogue voltage on the differential output pins. The trick to to feed the peripheral with data sufficiently fast enough – 44,100 times per second – so that it always has a sample to output when required.

This is where the DMA (direct memory access) peripheral comes in. We can setup the DMA peripheral to transfer data from a 256-word buffer directly to the DAC without any involvement by the processor itself. When the DMA peripheral has finished sending data from that buffer, it swaps to an alternate buffer, and continues sending data seamlessly from there.

The processor is only activated when a buffer becomes empty, which is its signal to fill the empty buffer with more data from the memory card. This

might sound complicated, and setting it all up is, but once done correctly the code is very simple.

By carefully monitoring the code execution (with the use of a few carefully placed pin toggles and an oscilloscope) we were able to determine that, at a clock rate of 78MHz, the system was *just* capable of managing the throughput – the limiting factor being how quickly we could read data from the card (remembering that the data is stored as a series of fragments in a filesystem).

With the code running there was just one thing left to do – listen to the output. Now, we have to admit at this point that enthusiasm and excitement took over, so rather than hooking the output up to a proper amplifier, we just fed it straight into a pair of headphones. Not expecting much, but hoping to hear something. Image our surprise when we heard crystal clear, hi-fidelity playback!

Through a proper amplifier the performance was even better. Thanks to the over-sampling and differential output no noise could be heard, even when the wav file finished playing and the volume was turned up to full. This was even more surprising given the crude circuit layout on a breadboard. The sound quality was on par with a CD player.

Source code layout

The final list of files is shown in Fig. 2. Note that most of these are supplied by Microchip; only main.c is original, containing all of our project-specific code. The file **HardwareProfile.h** has been modified to identify which port pins the SDMedia card is connected to, as mentioned earlier. The main code is very simple and easily extended; there is ample room left within the processor memory.

There are some obvious directions in which this project could be taken. How about your own, personalised music player? Or a self-contained drum synthesiser? (Which is what we are working on now?) Or perhaps, the next Halloween Howler, with some really spooky sound effects for next Halloween? Do let us know!

PLEASE TAKE NOTE

Time Delay Photoflash Trigger *(Feb '11)*

Page 16, Fig.3. Unfortunately, transistor Q3 is shown the wrong way round. The 'flat' of the transistor's body should be facing the 4.7kΩ resistor – ie, the collector pin should go to the anode (A) of LED1. The photograph on page 17 is correct.

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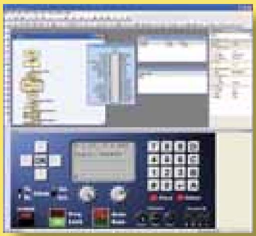
ELECTRONICS CD-ROMS

FLOWCODE 4®
NO CODING, NO LIMITS...

Flowcode 4 is one of the World's most advanced graphical programming languages for microcontrollers. The great advantage of Flowcode is that it allows those with little experience to create complex electronic systems in minutes.

Flowcode's graphical development interface allows engineers to construct a complete electronic system on-screen, develop a program based on standard flow charts, simulate the system and then produce hex code for PICmicro® microcontrollers, AVR microcontrollers, ARM microcontrollers, dsPIC and PIC24 microcontrollers.

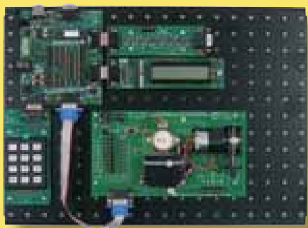


Design

Flowcode contains standard flow chart icons and electronic components that allow to you to create a virtual electronic system on screen. Drag icons and components onto the screen to create a program, then click on them to set properties and actions.

Simulate

Once your system is designed you can use Flowcode to simulate it in action. Design your system on screen, test the system's functionality by clicking on switches or altering sensor or input values, and see how your program reacts to the changes in the electronic system.



Download

When you are happy with your design click one button to send the program directly to your microcontroller based target. Targets include a wide range of microcontroller programmers, upstream E-blocks boards, the Formula Flowcode robot, the MIAC industrial controller, or your own system based on ECIO technology.

FlowKit

The FlowKit can be connected to hardware systems to provide a real time debug facility where it is possible to step through the Flowcode program on the PC and step through the program in the hardware at the same time. The FlowKit can be connected to your own hardware to provide In-Circuit Debug to your finished designs.

PRICES

Prices for each of the CD-ROMs above are: ***(Order form on third page)***

(UK and EU customers add VAT to 'plus VAT' prices)

Hobbyist/Student	**£45.95**	**inc VAT**
Professional (Schools/HE/FE/Industry)	**£149**	**plus VAT**
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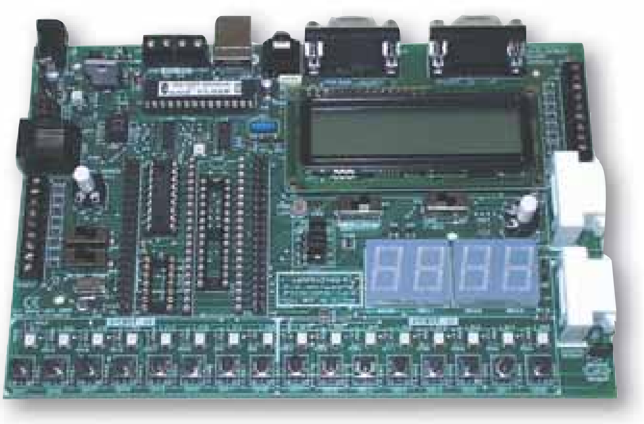
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Can be powered by USB (no power supply required)



£161 including VAT and postage, supplied with USB cable and programming software

SOFTWARE

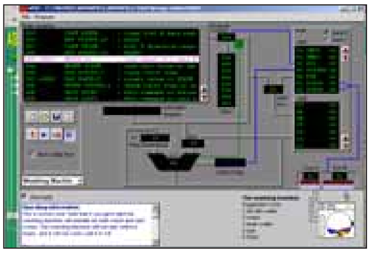
ASSEMBLY FOR PICmicro V3

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84 PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

● Comprehensive instruction through 45 tutorial sections ● Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator ● Tests, exercises and projects covering a wide range of PICmicro MCU applications ● Includes MPLAB assembler ● Visual representation of a PICmicro showing architecture and functions ● Expert system for code entry helps first time users ● Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.) ● Imports MPASM files.

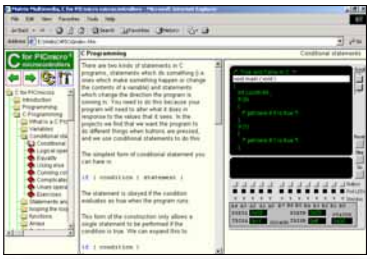


'C' FOR 16 Series PICmicro Version 4

The C for PICmicro microcontrollers CD-ROM is designed for students and professionals who need to learn how to program embedded microcontrollers in C. The CD-ROM contains a course as well as all the software tools needed to create Hex code for a wide range of PICmicro devices – including a full C compiler for a wide range of PICmicro devices.

Although the course focuses on the use of the PICmicro microcontrollers, this CD-ROM will provide a good grounding in C programming for any microcontroller.

● Complete course in C as well as C programming for PICmicro microcontrollers ● Highly interactive course ● Virtual C PICmicro improves understanding ● Includes a C compiler for a wide range of PICmicro devices ● Includes full Integrated Development Environment ● Includes MPLAB software ● Compatible with most PICmicro programmers ● Includes a compiler for all the PICmicro devices.



Minimum system requirements for these items: Pentium PC running, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.
Flowcode will run on XP or later operating systems

FLOWCODE FOR PICmicro V4

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the Version 3 development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
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- Full on-screen simulation allows debugging and speeds up the development process.
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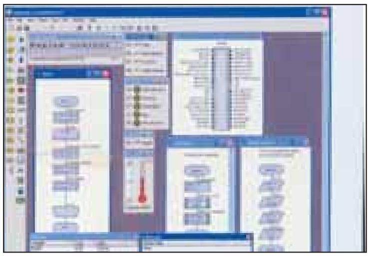
- Produces ASM code for a range of 18, 28 and 40-pin devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

New features of Version 4 include panel creator, in circuit debug, virtual networks, C code customisation, floating point and new components. The Hobbyist/Student version is limited to 4K of code (8K on 18F devices)



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Professional 10 user (Network Licence)	**£350**	**plus VAT**
Site Licence	**£699**	**plus VAT**
Flowcode Professional (Schools/HE/FE/Industry)	**£149**	**plus VAT**
Flowcode 10 user (Network Licence)	**£399**	**plus VAT**
Flowcode Site Licence	**£799**	**plus VAT**

NET WORK

by Alan Winstanley

Hacking the box

IN RECENT editions of *Net Work*, I highlighted the evolution of the home area network, in which a panoply of entertainment devices arrives Internet-aware, ready to connect to a router or home media server using Wi-Fi or Ethernet. My Humax HDR-FOX T2 digital TV recorder mentioned in the October issue hooks to my Wi-Fi using a cheap dongle sourced from eBay. Users of the Humax forum (**www.hummy.tv**) suggest a Realtek chipset is required in the dongle, and I found a Tenda-brand dongle connected successfully too. Very occasionally, the delivery stutters due to the lack of ADSL bandwidth or Wi-Fi interference.

Just like our editor's (see *Editorial*, Nov'11 *EPE*), my TV is a bulbous Sony Trinitron CRT, which does me fine, but thanks to the Humax Personal Video Recorder (PVR) I can also view YouTube or BBC iPlayer programmes on my television. The network Portal feature of the Humax PVR is still in beta, so some glitches are to be expected. I found that a sizeable number of YouTube videos don't load at all, and the Search feature is also pretty basic, but it's early days so let's be kind and not overlook the amazing technology being used to stream digital content into our lounge. All sorts of hacks and customisations are described in the Humax forum, and newcomers will appreciate the welcoming and friendly atmosphere there.

If you don't need a recorder, but would like to access your media on TV over a home network, then the interesting-looking D-Link Boxee Box is an HDMI-compatible media player that streams Internet-based TV, web videos or your music/video collection to your TV. You can also experience Boxee on a Windows, Mac, iPad or Linux computer using free software from **www.boxee.tv**.

For much of Britain, the switch to digital television is looming large, and our own consulting editor, Dave, was recently heard to be contemplating the effects of digital switchover at home. As a sign of the pervasive spread of the Internet, with Dave on the phone one evening, I soon logged onto Google Street View and saw which way Dave's roof TV antenna was pointing. We noted that after switchover it would have to swing 180 degrees to the new digital TV mast, but some neighbouring trees will no longer be in the way! Thanks to Tina's help, Dave found a supplier of a new aerial and aerial signal booster, while I managed to sort out some travel directions using Streetview once again.

PVR to DVD

Net Work isn't a computer column, but having already 'gone digital' myself, I was soon musing over the technical hurdles of burning TV programmes from my PVR box onto DVD, so that I could archive them away safely. My PVR is full of programmes such as *How It's Made*, including how xenon tubes, pinball machines and light-bulbs are fabricated. But how to store them for future enjoyment? It's easy to fill up a hard drive with programmes, so *EPE* readers may like some brief ideas for preserving hard disk recordings on DVD.

One direct way is to plug a DVD recorder into a set-top box; however, expert users are already hacking into the Humax PVR and transferring files over their home network via FTP. For the rest of us the simplest way is to transport files on a portable drive before using a PC or laptop to burn a disk.

The Humax HDR-FOX T2 is essentially a Linux computer that will happily read certain media files on a USB hard drive (NTFS/ FAT) for playing directly on a TV. In order to write files to the external USB drive though, the disk must be formatted for Linux ext3. I found Paragon Partition Manager Free Edition for Windows from **www.paragon-software.com** does not format a Linux disk, but you can buy a 10-day licence for $9.95 that does. The marvellous Windows-like Linux distribution called YLMF OS from **www.ylmf.org** formatted a USB drive in ext4, which the PVR did not recognise; you can experience Linux for yourself by booting a PC with YLMF OS on CD.

So for now, I let the Humax handle the job of formatting an external Linux drive. Stored TV programmes can be queued for copying onto it, which can take a long time! In order to import files onto a Windows PC ready for DVD burning, I found the free Linux Reader 2.0 for Windows courtesy of disk recovery specialists Disk Internals (**www.diskinternals.com**). Paragon software offers free ExtBrowser (not tried). After importing them into Windows, an MPEG or a DVD can be made.

After much browsing around on the web I settled on the highly-rated VideoRedo TV Suite editor – it isn't cheap, but it's a worthwhile one-time investment which produces an MPEG from .ts (transport stream) files at lightning speed. Adverts can be edited out too. DVDs can sometimes take hours to encode, but a batch of TV programmes can be prepared for processing overnight and VideoRedo can automatically burn them onto a menu-driven DVD. Both PAL and NTSC are supported.

Trial versions of VideoRedo can be downloaded from **www.videoredo.com**, and if you're keen on archiving your favourite TV programs over the forthcoming Christmas holidays, you'll want to give these downloads a try. Doubtless, readers will have other options and techniques, which I'll be pleased to share with fellow readers.

Some synology

I mentioned briefly the use of a home media server, and I recently added to my own router a Synology Diskstation DS211J, a RAID network-attached storage (NAS) unit that hosts media files on twin SATA disks (not supplied by default) for security and effortless streaming over the home network onto the TV. This DLNA-compliant home server makes you smile: it's compact and near-silent with an excellent GUI, and the Humax PVR usually finds it straight away, streaming photos and movie clips over Wi-Fi. PC files can be shared over the network or data backups taken onto the drive, and the device supports IP camera surveillance and much more. Details of the Synology DS211J are at: **www.synology.com**

The Synology DS211J RAID-style NAS box is DLNA-compliant, compact and near-silent, with many features to please the home network enthusiast.

In February 1984, *Everyday Electronics* mentioned the launch of the world's first multifunctional digital TV, from Panasonic in Japan. It had 30% fewer components than analogue sets, and it was viewdata/hifi and home computer compatible. Digital TV was hailed in 1984 as 'marking a new generation that will serve as the focal point for the home information centre of the future.'

How true a prophecy that is becoming. Handling an entire home media library wirelessly still requires a little expertise, but the forward trends are very clear and there are many exciting developments to come in the future.

Wi-Fi Christmas

With my thoughts now turning towards Christmas shopping, I found myself in a Tesco supermarket poking the screen of an iPad2. It's too dainty for my tastes, but the svelte lines of Apple's encapsulation are tactile, and the seductive simplicity of the visual interface is impressive.

Amazon has expanded its Kindle e-Book reader range that I mentioned last month, with smaller and lighter bodies, but the same six-inch diagonal high contrast e-ink screen, which unlike an iPad2, is not backlit – the jury's out, but I concluded that after turning some digital book pages on an iPad2 (while reading *Winnie the Pooh*, of course!) my eyes might eventually feel the strain caused by the glare of those white pages on the iPad's powerful LED-backlit screen.

The Kindle Fire is Amazon's first colour tablet. It promises smarter, faster browsing thanks to its Silk content delivery architecture.

Amazon Kindles now start from £89 ($135) for the keyboard-free model, but USA Kindle users can choose optional on-screen sponsored screensaver versions, which bring the price down to just $79, or $109 for commercial-free Kindles. A new colour model is waiting in the wings: the Kindle Fire, is Amazon's first colour tablet with a seven-inch touchscreen due to launch in the USA when you read this.

The Fire promises swifter websurfing thanks to the way in which Amazon's formidable EC2 processing 'cloud' is harnessed to deliver web page content intelligently, partnering with the new Amazon Silk web browser found on every Fire (see **www.amazon.com/silk**).

The Amazon Kindle Fire will weigh in at $199, and for now, is only available in the US. Amazon promises a host of movies, books, apps and games. The Fire also has a built-in webmail client and PDF reader. It's wireless and acts as a standalone unit that doesn't need a computer, Amazon says. The UK prices have not been announced, but I predict the (8GB) Kindle Fire will probably land in the UK at £199 – still half the price of the cheapest (16GB) iPad2.

Last, some Christmas gift suggestions with a distinctively *Net Work* flavour. With festive feasting in mind, the WiThings Wi-Fi Digital Bathroom Scales securely uploads your weight, body fat mass and BMI data for display in a web browser or iPhone app (supplied), or alternatively uses computer software to monitor progress. One user claims it supports Linux as well. It's family friendly, recognising up to eight family users individually. While you're at it, test your pulse and circulation using WiThing's Blood Pressure Monitor (for iPhone and iPad only). I still love my Pure Evoke Flow portable Internet radio (rechargeable battery and RF remote control available separately), which uses Wi-Fi to pull in Internet-based radio channels. Radios can be configured over the web at the Pure Lounge portal site: **www.pure.com/thelounge**.

The Meccano Spykee Wi-Fi Spy Robot is a pint-sized 'Short-Circuit'-style mobile robot with webcam VOIP, MP3, flashlight and remote IP control. Meccano has told me that it's being discontinued, and a new model is a couple of years away. (Meccano is known as Erector in the USA.) Spykee's source code is downloadable, and the legacy product is available online (Conrad, Amazon, eBay) but stocks are running low, so grab one while you can. See: **www.spykeeworld.com**.

Digital photo frames have come of age, and Kodak offers the Kodak Pulse Digital Frame with seven-inch TFT touchscreen and Wi-Fi to stream your photos hosted on the Kodak Pulse website, or via your email account or Facebook, Flikr, SD card, USB and more. See **www.kodakpulse.com** for full details.

Many of these items are available on Amazon, and websites such as **www.camelcamelcamel.com** can alert you automatically when an Amazon item drops in price. Many merchants also have eBay outlets, and in October eBay UK announced its own 'shopping cart', which allows items from multiple vendors to be purchased in a single checkout transaction, rather than individually.

The best Christmas present of all might be the gift of an electronic kit for a youngster to tackle as their first project. You need look no further than the superb range of top-quality Velleman kits sold by ESR Electronic Components (**www.esr.co.uk**), or Quasar Electronics (**www.quasarelectronics.co.uk**) – see adverts in this issue. I can recommend Velleman kits without question; they are professionally designed, fully silk-screen printed and their successful completion will delight and boost the confidence of the budding electronics novice enormously. Add a gift of a quality Antex soldering iron and bench stand, and you'll have the perfect electronic hobbyist's Christmas.

You can email me at: **alan@epemag.demon.co.uk**.

WiThings' Wi-Fi Digital Bathroom Scales will upload your data securely over wifi for viewing online or on an iPhone.

READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

WIN AN ATLAS LCR ANALYSER WORTH £79

An Atlas LCR Passive Component Analyser, kindly donated by Peak Electronic Design Ltd, will be awarded to the author of the Letter Of The Month. The Atlas LCR automatically measures inductance from 1mH to 10H, capacitance from 1pF to 10,000µF and resistance from 1Ω to 2MΩ with a basic accuracy of 1%. www.peakelec.co.uk

All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

★ LETTER OF THE MONTH ★

Circuit Surgery needs a little surgery

Dear editor
I'm having trouble with the algebra in September's *Circuit Surgery* (top of the right-most column, page 60) and wondered if you or Ian could tell me what I'm doing wrong.

First, I substituted Rp = R3 / (R3 + 1) into the equation G = 2Rp / (R3 + Rp) but got the reciprocal of your result, achieving R3 = (2 – 2G) / G. I showed this result to my friend who teaches maths and physics (I help him by making practical demonstrations – and explain the electrical/electronics part of the subject when he gets stuck!). He came up with my result too.

I agree with the final equation as printed, G of one-third results in R3 = 0.25. However, putting this R3 value into the middle equation gives Rp = 0.2 and, when this Rp value is applied to the topmost equation, G = (2 x 0.2) / (0.25 + 0.2) = eight-ninths (not one-third). Any ideas?!

Godfrey Manning G4GLM, by email

Ian Bell replies

Thanks Godfrey, for spotting the error – it certainly surprised me on first reading your email that the final equation was apparently 'upside down', but also correct! The problem is in fact due to a typo in the first equation (for the gain of Fig.11), which should have been:

$$G = \frac{2R_P}{(R1A + R_P)}$$

That is, R1A replaces R3 in the original, incorrect equation. The bottom half of this equation is the total resistance of the potential divider: the sum of R1A and Rp.

Rp is the parallel combination of R3 and R1B and forms the bottom half of the potential divider, with R1A as the top half. As R1A = 1 we can rewrite the equation as:

$$G = \frac{2R_P}{(1 + R_P)}$$

The value of Rp was correctly stated as:

$$R_P = \frac{R3}{(R3 + 1)}$$

Now, when we substitute R_P into the equation for G we obtain the expression for R3 given in the article:

$$R3 = \frac{G}{(2 - 2G)}$$

We now have G =1/3, which gives R3 = 0.25 and R_P = 0.2 from the middle equation and G = 1/3, as expected, from the corrected first equation.

It is, I suppose, a bit of fluke that the erroneous resistor designation happened to lead to the reciprocal of the result when the substitution was made.

...and a follow up from Godfrey

Dear Ian
Thanks for putting me (and Hitendra, my physics-teaching neighbour) out of our collective misery – we were not imagining non-existent reciprocals!

You can now see precisely why I like the Circuit Surgery feature, it gives me more to think about than is first suggested by the immediate question – and there's usually a bit of algebra thrown in to keep the brain from seizing up! At my age, I need all the mental exercise that can be provided (hint: I've finally reached the legal minimum age – for retirement)

Regards and thanks again, Godfrey Manning

Thanks for the 'thanks' Godfrey – you seem a long way from seizing up, and we appreciate you spotting our typo!

Matt Pulzer, editor

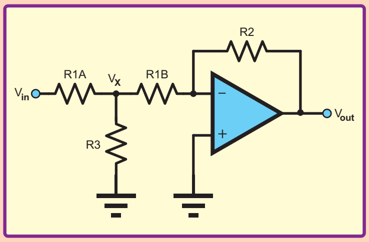

Fig.11. from September 2011 EPE *Stable inverting attenuator*

DIRECT BOOK SERVICE

The books listed have been selected by *Everyday Practical Electronics* editorial staff as being of special interest to everyone involved in electronics and computing. They are supplied by mail order direct to your door. Full ordering details are given on the last book page.

FOR A FURTHER SELECTION OF BOOKS SEE THE NEXT TWO ISSUES OF *EPE*

3 **All prices include UK postage**

ELECTRONICS TEACH-IN BUNDLE – SPECIAL BUNDLE PRICE £14 FOR PARTS 1, 2 & 3

ELECTRONICS TEACH-IN 2 CD-ROM USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has now been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

The Microchip items are: MPLAB Integrated Development Environment V8.20; Microchip Advance Parts Selector V2.32; Treelink; Motor Control Solutions; 16-bit Embedded Solutions; 16-bit Tool Solutions; Human Interface Solutions; 8-bit PIC Microcontrollers; PIC24 Micrcontrollers; PIC32 Microcontroller Family with USB On-The-Go; dsPIC Digital Signal Controllers.

CD-ROM **Order code ETI2 CD-ROM** **£9.50**

FREE CD-ROM

ELECTRONICS TEACH-IN 3

The three sections of this book cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on various circuit design and application problems – everything from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The free cover-mounted CD-ROM is the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial), together with simulations of the circuits in the Teach-In 1 series, plus Flowcode (a limited version) a high level programming system for PIC microcontrollers based on flowcharts.

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC. There is also a MW/LW Radio project in the series. The contents of the book and Free CD-ROM have been reprinted from past issues of *EPE*.

160 pages **Order code ETI3** **£8.50**

Book and CD-ROMs **Order code ETIBUNDLE** Bundle Price **£14.00**

ROBOTICS

INTRODUCING ROBOTICS WITH LEGO MINDSTORMS
Robert Penfold

Shows the reader how to build a variety of increasingly sophisticated computer controlled robots using the brilliant Lego Mindstorms Robotic Invention System (RIS). Initially covers fundamental building techniques and mechanics needed to construct strong and efficient robots using the various "click-together" components supplied in the basic RIS kit. Then explains in simple terms how the "brain" of the robot may be programmed on screen using a PC and "zapped" to the robot over an infra-red link. Also, shows how a more sophisticated Windows programming language such as Visual BASIC may be used to control the robots.

Detailed building and programming instructions provided, including numerous step-by-step photographs.

288 pages - large format **Order code BP901** **£14.99**

MORE ADVANCED ROBOTICS WITH LEGO MINDSTORMS – Robert Penfold

Shows the reader how to extend the capabilities of the brilliant Lego Mindstorms Robotic Invention System (RIS) by using lego's own accessories and some simple home constructed units. You will be able to build robots that can provide you with 'waiter service' when you clap your hands, perform tricks, 'see' and avoid objects by using 'bats radar', or accurately follow a line marked on the floor. Learn to use additional types of sensors including rotation, light, temperature, sound and ultrasonic and also explore the possibilities provided by using an additional (third) motor. For the less experienced, RCX code programs accompany most of the featured robots. However, the more adventurous reader is also shown how to write programs using Microsoft's VisualBASIC running with the ActiveX control (Spirit.OCX) that is provided with the RIS kit.

Detailed building instructions are provided for the featured robots, including numerous step-by-step photographs. The designs include rover vehicles, a virtual pet, a robot arm, an 'intelligent' sweet dispenser and a colour conscious robot that will try to grab objects of a specific colour.

198 pages **Order code BP902** **£14.99**

ANDROIDS, ROBOTS AND ANIMATRONS
Second Edition – John Iovine

Build your own working robot or android using both off-the-shelf and workshop constructed materials and devices. Computer control gives these robots and androids two types of artificial intelligence (an expert system and a neural network). A lifelike android hand can be built and programmed to function doing repetitive tasks. A fully animated robot or android can also be built and programmed to perform a wide variety of functions.

The contents include an Overview of State-of-the-Art Robots; Robotic Locomotion; Motors and Power Controllers; All Types of Sensors; Tilt; Bump; Road and Wall Detection; Light; Speech and Sound Recognition; Robotic Intelligence (Expert Type) Using a Single-Board Computer Programmed in BASIC; Robotic Intelligence (Neutral Type) Using Simple Neural Networks (Insect Intelligence); Making a Lifelike Android Hand; A Computer-Controlled Robotic Insect Programmed in BASIC; Telepresence Robots With Actual Arcade and Virtual Reality Applications; A Computer-Controlled Robotic Arm; Animated Robots and Androids; Real-World Robotic Applications.

224 pages **Order code MGH1** **£16.99**

RADIO

BASIC RADIO PRINCIPLES AND TECHNOLOGY
Ian Poole

Radio technology is becoming increasingly important in today's high technology society. There are the traditional uses of radio which include broadcasting and point to point radio as well as the new technologies of satellites and cellular phones. All of these developments mean there is a growing need for radio engineers at all levels.

Assuming a basic knowledge of electronics, this book provides an easy to understand grounding in the topic.

Chapters in the book: Radio Today, Yesterday, and Tomorrow; Radio Waves and Propagation; Capacitors, Inductors, and Filters; Modulation; Receivers; Transmitters; Antenna Systems; Broadcasting; Satellites; Personal Communications; Appendix – Basic Calculations.

263 pages **Order code NE30** **£28.99**

PROJECTS FOR RADIO AMATEURS AND S.W.L.S.

R. A. Penfold

This book describes a number of electronic circuits, most of which are quite simple, which can be used to enhance the performance of most short wave radio systems.

The circuits covered include: An aerial tuning unit; A simple active aerial; An add-on b.f.o. for portable sets; A wavetrap to combat signals on spurious responses; An audio notch filter; A parametric equaliser; C.W. and S.S.B. audio filters; Simple noise limiters; A speech processor; A volume expander.

Other useful circuits include a crystal oscillator, and RTTY/C.W. tone decoder, and a RTTY serial to parallel converter. A full range of interesting and useful circuits for short wave enthusiasts.

92 pages **Order code BP304** **£4.45**

AN INTRODUCTION TO AMATEUR RADIO
I. D. Poole

Amateur radio is a unique and fascinating hobby which has attracted thousands of people since it began at the turn of the last century. This book gives the newcomer a comprehensive and easy to understand guide through the subject so that the reader can gain the most from the hobby. It then remains an essential reference volume to be used time and again. Topics covered include the basic aspects of the hobby, such as operating procedures, jargon and setting up a station. Technical topics covered include propagation, receivers, transmitters and aerials etc.

150 pages **Order code BP257** **£5.49**

COMPUTERS AND COMPUTING

BUILD YOUR OWN PC – Fourth Edition
Morris Rosenthal

More and more people are building their own PCs. They get more value for their money, they create exactly the machine they want, and the work is highly satisfying and actually fun. That is, if they have a unique beginner's guide like this one, which visually demonstrates how to construct a computer from start to finish.

Through 150 crisp photographs and clear but minimal text, readers will confidently absorb the concepts of computer building. The extra-big format makes it easy to see what's going on in the pictures. The author goes 'under the hood' and shows step-by-step how to create a Pentium 4 computer or an Athlon 64 or Athlon 64FX, covering: What first-time builders need to know; How to select and purchase parts; How to assemble the PC; How to install Windows XP. The few existing books on this subject, although outdated, are in steady demand. This one delivers the expertise and new technology that fledgling computer builders are looking for.

224 pages - large format **Order code MGH2** **£16.99**

PROGRAMMING 16-BIT PIC MICROCONTROLLERS IN C – LEARNING TO FLY THE PIC24 Lucio Di Jasio (Application Segments Manager, Microchip, USA)

A Microchip insider tells all. Focuses on examples and exercises that show how to solve common, real-world design problems quickly. Includes handy checklists to help readers perform the most common programming and debugging tasks. FREE CD-ROM includes source code in C, the Microchip C30 compliler, and MPLAB SIM software, so that readers gain practical, hands-on programming experience.

Until recently, PICs didn't have the speed and memory necessary for use in designs such as video- and audio-enabled devices. All that changed with the introduction of the 16-bit PIC family, the PIC24. This new guide teaches readers everything they need to know about the architecture of these chips, how to program them, how to test them and how to debug them. Lucio's common-sense, practical, hands-on approach starts out with basic functions and guides the reader step-by-step through even the most sophisticated programming scenarios.

Experienced PIC users and newcomers alike will benefit from the text's many thorough examples, which demonstrate how to nimbly side-step common obstacles and take full advantage of all the 16-bit features.

496 pages +CD-ROM **Order code NE45** **£38.00**

NEW FULL COLOUR COMPUTING BOOKS

WINDOWS 7 – TWEAKS, TIPS AND TRICKS
Andrew Edney
This book will guide you through many of the exciting new features of Windows 7. Microsoft's latest and greatest operating system. It will provide you with useful hints, tips and warnings about possible difficulties and pitfalls. This book should enable you to get much more out of Windows 7 and, hopefully, discover a few things that you may not have realised were there.

Among the topics covered are: A brief overview of the various versions of Windows 7. How to install and use Upgrade Advisor, which checks to see if your computer meets the minimum requirements to run Windows 7 and that your software and drivers are supported by Windows 7. How to use Windows Easy Transfer to migrate your data and settings from your Vista or XP machine to your new Windows 7 computer. Exploring Windows 7 so that you will become familiar with many of its new features and then see how they contrast with those of earlier versions of Windows. How to connect to a network and create and use Home Groups to easily share your pictures, videos, documents, etc.,with the minimum of hassle. Why Windows Live Essentials is so useful and how to download and install it. A brief introduction to Windows Media Center. The use of Action Center, which reports security and maintenance incidents. Windows Memory Diagnostic to detect the fairly common problem of faulty memory and Troubleshooting tools.

120 pages **Order code BP708** **£8.49**

HOW TO BUILD A COMPUTER MADE EASY
R.A. Penfold
Building your own computer is a much easier than most people realise and can probably be undertaken by anyone who is reasonably practical. However, some knowledge and experience of using a PC would be beneficial. This book will guide you through the entire process. It is written in a simple and straightforward way with the explanations clearly illustrated with numerous colour photographs.

The book is divided into three sections: *Overview and preparation* – Covers understanding the fundamentals and choosing the most suitable component parts for your computer, together with a review of the basic assembly. *Assembly* – Explains in detail how to fit the component parts into their correct positions in the computer's casing, then how to connect these parts together by plugging the cables into the appropriate sockets. No soldering should be required and the only tools that you are likely to need are screwdrivers, small spanners and a pair of pliers.

BIOS and operating system – This final section details the setting up of the BIOS and the installation of the Windows operating system, which should then enable all the parts of your computer to work together correctly. You will then be ready to install your files and any application software you may require.

The great advantage of building your own computer is that you can 'tailor' it exactly to your own requirements. Also, you will learn a tremendous amount about the structure and internal workings of a PC, which will prove to be invaluable should problems ever arise.

120 pages **Order code BP707** **£8.49**

AN INTRDUCTION TO eBAY FOR THE OLDER GENERATION
Cherry Nixon
eBay is an online auction site that enables you to buy and sell practically anything from the comfort of your own home. eBay offers easy access to the global market at an amazingly low cost and will enable you to turn your clutter into cash.

This book is an introduction to eBay.co.uk and has been specifically written for the over 50s who have little knowledge of computing. The book will, of course, also apply equally to all other age groups. The book contains ideas for getting organised for long term safe and successful trading. You will learn how to search out and buy every conceivable type of thing.The book also shows you how to create auctions and add perfect pictures. There is advice on how to avoid the pitfalls that can befall the inexperienced.

Cherry Nixon is probably the most experienced teacher of eBay trading in the UK and from her vast experience has developed a particular understanding of the issues and difficulties normally encountered by individuals.

So, if you are new to computers and the internet and think of a mouse as a rodent, then this is the book for you!

120 pages **Order code BP709** **£8.49**

GETTING STARTED IN COMPUTING FOR THE OLDER GENERATION
Jim Gatenby
You can learn to use a computer at any age and this book will help you acheive this. It has been especially written for the over 50s, using plain English and avoiding technical jargon wherever possible. It is lavishly illustrated in full colour.

Among the many practical and useful subjects that are covered in this book are: Choosing the best computing system for your needs. Understanding the main hardware components of your computer. Getting your computer up and runnning in your home. Setting up peripheral devices like printers and routers. Connecting to the internet using wireless broadband in a home with one or more computers. Getting familiar with Windows Vista and XP the software used for operating and maintaining your computer. Learning about Windows built-in programs such as Windows Media Player, Paint and Photo Gallery.

Plus, using the Ease of Access Center to help if you have impaired eyesight, hearing or dexterity problems. Installing and using essential software such as Microsoft Office suite. Searching for the latest information on virtually any subject. Keeping in touch with friends and family using e-mail. Keeping your computer running efficiently and your valuable data files protected against malicious attack.

This book will help you to gain the basic knowledge needed to get the most out of your computer and, if you so wish, give you the confidence to even join a local computer class.

120 pages **Order code BP704** **£8.49**

THEORY AND REFERENCE

ELECTRONIC CIRCUITS – FUNDAMENTALS & APPLICATIONS
Third Edition
Mike Tooley
A comprehensive reference text and practical electronics handbook in one volume – at an affordable price!

New chapter on PIC microcontrollers – the most popular chip family for use in project work by hobbyists and in colleges and universities.

New companion website: spreadsheet design tools to simplify circuit calculations; circuit models and templates to enable virtual simulation; a bank of on-line questions for lecturers to set as assignments, and on-line self-test multiple choice questions for each chapter with automatic marking, to enable students to continually monitor their progress and understanding.

The book's content is matched to the latest pre-degree level courses, making this an invaluable reference for all study levels, and its broad coverage is combined with practical case studies, based in real-world engineering contexts throughout the text.

The unique combination of a comprehensive reference text, incorporating a primary focus on practical applications, ensures this text will prove a vital guide for students and also for industry-based engineers, who are either new to the field of electronics, or who wish to refresh their knowledge.

400 pages **Order code NE43** **£25.99**

BEBOP TO THE BOOLEAN BOOGIE
Third Edition
Clive (Max) Maxfield
This book gives the 'big picture' of digital electronics. This indepth, highly readable, guide shows you how electronic devices work and how they're made. You'll discover how transistors operate, how printed circuit boards are fabricated, and what the innards of memory ICs look like. You'll also gain a working knowledge of Boolean Algebra and Karnaugh Maps, and understand what Reed-Muller logic is and how it's used. And there's much, MUCH more. The author's tongue-in-cheek humour makes it a delight to read, but this is a REAL technical book, extremely detailed and accurate.

Contents: Fundamental concepts; Analog versus digital; Conductors and insulators; Voltage, current, resistance, capacitance and inductance; Semiconductors; Primitive logic functions; Binary arithmetic; Boolean algebra; Karnaugh maps; State diagrams, tables and machines; Analog-to-digital and digital-to-analog; Integrated circuits (ICs); Memory ICs; Programmable ICs; Application-specific integrated circuits (ASICs); Circuit boards (PWBs and DWBs); Hybrids; Multichip modules (MCMs); Alternative and future technologies.

500 pages **Order code BEB1** **£32.99**

BEBOP BYTES BACK (and the Bebopter Computer Simulator) CD-ROM
Clive (Max) Maxfield and Alvin Brown

CD-ROM

This follow-on to Bebop to the Boolean Boogie is a multimedia extravaganza of information about how computers work. It picks up where "Bebop I" left off, guiding you through the fascinating world of computer design . . . and you'll have a few chuckles, if not belly laughs, along the way. In addition to over 200 megabytes of mega-cool multimedia, the CD-ROM contains a virtual microcomputer, simulating the motherboard and standard computer peripherals in an extremely realistic manner. In addition to a wealth of technical information, myriad nuggets of trivia, and hundreds of carefully drawn illustrations, the CD-ROM contains a set of lab experiments for the virtual microcomputer that let you recreate the experiences of early computer pioneers. if you're the slightest bit interested in the inner workings of computers, then don't dare to miss this!

Over 800 pages in Adobe Acrobat format

CD-ROM **Order code BEB2 CD-ROM** **£21.95**

FUNDAMENTAL ELECTRICAL AND ELECTRONIC PRINCIPLES
Third Edition
C. R. Robertson
Covers the essential principles that form the foundations for electrical and electronic engineering courses. The coverage of this new edition has been carefully brought in line with the core unit 'Electrical and Electronic Principles' of the 2007 BTEC National Engineering specification. This qualification from Edexcel attracts more than 10,000 students per year.

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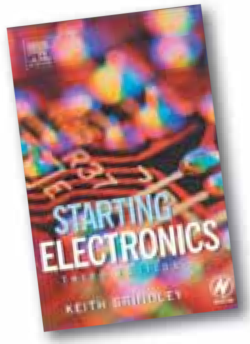

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PROJECT BUILDING AND TESTING

ELECTRONIC PROJECT BUILDING FOR BEGINNERS
R. A. Penfold

This book is for complete beginners to electronic project building. It provides a complete introduction to the practical side of this fascinating hobby, including the following topics:

Component identification, and buying the right parts; resistor colour codes, capacitor value markings, etc; advice on buying the right tools for the job; soldering; making easy work of the hard wiring; construction methods, including stripboard, custom printed circuit boards, plain matrix boards, surface mount boards and wire-wrapping; finishing off, and adding panel labels; getting "problem" projects to work, including simple methods of fault-finding.

In fact everything you need to know in order to get started in this absorbing and creative hobby.

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A unique hands-on guide for anyone working with valve (tube in USA) audio equipment – as an electronics experimenter, audiophile or audio engineer.

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While fibre-optic cables may have potential advantages over ordinary electric cables, for the electronics enthusiast it is probably their novelty value that makes them worthy of exploration. Fibre-optic cables provide an innovative interesting alternative to electric cables, but in most cases they also represent a practical approach to the problem. This book provides a number of tried and tested circuits for projects that utilize fibre-optic cables.

The projects include:- Simple audio links, F.M. audio link, P.W.M. audio links, Simple d.c. links, P.W.M. d.c. link, P.W.M. motor speed control, RS232C data links, MIDI link, Loop alarms, R.P.M. meter.

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GETTING THE MOST FROM YOUR MULTIMETER
R. A. Penfold

This book is primarily aimed at beginners and those of limited experience of electronics. Chapter 1 covers the basics of analogue and digital multimeters, discussing the relative merits and the limitations of the two types. In Chapter 2 various methods of component checking are described, including tests for transistors, thyristors, resistors, capacitors and diodes. Circuit testing is covered in Chapter 3, with subjects such as voltage, current and continuity checks being discussed.

In the main little or no previous knowledge or experience is assumed. Using these simple component and circuit testing techniques the reader should be able to confidently tackle servicing of most electronic projects.

102 pages — **Order code BP239** — **£5.49**

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NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail. Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

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Next Month

GPS Car Computer

This project was inspired by requests from a number of readers. They said that our previous GPS module project was great for obtaining a precise time, but could we produce a project that used its full capabilities for use in a vehicle?

So, what we came up with includes: digital speedometer, over-speed alarm, fuel economy meter, distance and time to destination, altitude in metres, heading and compass, current latitude and longitude… and, of course, a digital clock with GPS accuracy.

WIB: Web server In a Box – Part 2

Next month, we show you how to connect our new Web server In a Box (WIB) to your modem/router and guide you step-by-step through the set-up details. We also show you how to activate a dynamic DNS service, so that you can access the WIB via the Internet. **Hosting a website has never been so cheap and easy!**

A balanced output board for the Stereo DAC

This add-on board is designed to provide a pair of balanced audio outputs for our popular High-Quality Stereo DAC (Sept-Nov 2011). Two 3-pin male XLR connectors are used for the new outputs, and they can either replace or augment the existing unbalanced outputs without affecting their crystal-clear performance.

JANUARY '12 ISSUE ON SALE 8 DECEMBER

Content may be subject to change

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